# *FLUVIAL GEOMORPHOLOGY AND SEDIMENT TRANSPORT CHARACTERISTICS OF THE WAINGANGA RIVER, CENTRAL INDIA*

A thesis submitted

in partial fulfillment of the requirements

for the degree of

**MASTER OF TECHNOLOGY**

by

**DOMABAPU B. BRAHMANKAR**

to the

**DEPARTMENT OF CIVIL ENGINEERING**

**INDIAN INSTITUTE OF TECHNOLOGY, KANPUR**

April, 1996

## CERTIFICATE

Certified that the work presented in this thesis entitled " *FLUVIAL GEOMORPHOLOGY AND SEDIMENT TRANSPORT OF THE WAINGANGA RIVER, CENTRAL INDIA"* has been carried out by **Domabapu B. Brahmankar (Roll No. 9410310)** under my supervision and has not been submitted elsewhere for a degree


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# ABSTRACT

The Wainganga river is one of the major tributaries of Godavari river in peninsular India with a catchment area of about 51,000 sq. km and total length of 606 km spread in the state of Maharashtra and Madhya Pradesh The Wainganga basin has varied rock formations including Precambrian rocks (granite gneisses) and Deccan traps covering the major portion of the basin and alluvial soils, laterite, granite, sandstone, shale, dolomite, mica, schist etc The major tributaries of the Wainganga river are Thel, Thanwar, Bagh, Chulband, Gadhvi, Khobragarhi, Kathani joining left bank and Hirri, Bawanthari, Kanhan and Mul joining the right bank The northern part of the basin is covered by Mahadeo hills and Satpura ranges of the average elevation 625 m above mean sea level The Wainganga river experiences the tropical climatic conditions with a monthly precipitation of 640 mm in monsoon season

The tear shaped Wainganga basin is mostly encountered with dendritic drainage pattern except in small portion of Ramtek and Bhandara region which are covered by parallel drainage pattern controlled by pronounced folds. The upstream reaches of the Kanhan river are dominated by rectangular drainage pattern as seen on remote sensing images. The common geomorphological features observed in the basin are point bars, channel bars, lakes uplands and rarely found geomorphic features are paleochannels, ox-bow lakes, swamps etc. The study of location of the Pench reservoir (Pench Project) with its pick up weir reveals that Pench reservoir is surrounded by broken and rugged topography making extremely difficult to bring out the canals. The planform of the Wainganga river is controlled by longitudinal gradient of the river resulting in deep and narrow cross-sections in the upstream and wide and shallow cross-sections in the downstream reaches.

The sediment size of the channel bed is reducing downward. The gradual decrease of the sorting coefficient and uniformity coefficient indicate very less contribution of the sediment in the downward reaches by small confluencing streams It has been observed from discharge-concentration relationships that there is a fall of suspended sediment concentration of all fractions at Ashti as compared with that of Pauni station Hence, the total sediment transport at Pauni is more than that of Ashti which gives the rate of aggradation of 5.996 t /m / yr. between Pauni and Ashti stations. The probable reason of higher sediment load at Pauni than Ashti may be lithological controls and land cover of the basin and hydrological characteristics and gradient changes along the river The reaches at Pauni station are dominated by alluvial soils yielding huge quantity of sediment while the reaches at Ashti region are covered by granite gneisses ( hard rocks) resulting lower sediment yield at downstream reaches than those of upstream reaches. The comparison of the sediment transport of the Wainganga river at Pauni and Ashti with other Indian rivers shows that the Wainganag river is not significantly active in terms of sediment transport.

# CONTENTS

## CHAPTER 3 : Hydrology and Sediment Transport



## CHAPTER 4 : Summary and Conclusions

# LIST OF FIGURES

# LIST OF TABLES

# CHAPTER 1

# INTRODUCTION

## 1.1 General

The Wainganga is one of the major tributaries of the Godavari river in peninsular India. The Wainganga basin has an area of about 51,000 sq. km traversing the Maharashtra state in the downstream and Madhya Pradesh in the upstream reaches of the river. The traversing length is of river is about 606 km from the Pipariya (Amagarh) in Seoni district of Madhya Pradesh to Ashti in Garhchiroli district of Maharashtra state flowing nearly in north-south direction.

The location map of the Wainganga basin is shown in Fig. 1 1 The Wainganga basin covers the central part of Indian subcontinent surrounded by the Narmada basin to its North, by the Indravati and the Mahanadi basin to the East, by lower Godavari basin to the South and by Wardha basin to the West. The Wainganga river finally confluences to the Godavari river and is called Pranhita river just before the confluence

The Wainganga river is confined between latitude of 19 $^{o}$ 41 ' 0" and 22 $^{o}$ 34 ' 5 " and longitude of 78 $^{o}$ 15 ' 0" and 80 $^{o}$ 38 ' 50" as shown in the location map. Along the Wainganga river there are four hydrological stations of the Central water commission (CWC) at Keolari and Kumhari in Madhya Pradesh and at Pauni and Ashti in Maharashtra. The meteorological stations of the Indian meteorological Department (IMD) are located at Sakoli (Bhandara), Pauni (Bhandara) and Mul (Chandrapur). All these sites are shown in the location map of the basin. The major cities in the basin are Nagpur (21.09$^{o}$ N & 79.09$^{o}$E ), Bhandara ( 21.09$^{o}$ & 79.42$^{o}$) and Balaghat (21.48$^{o}$& 80.15$^{o}$).

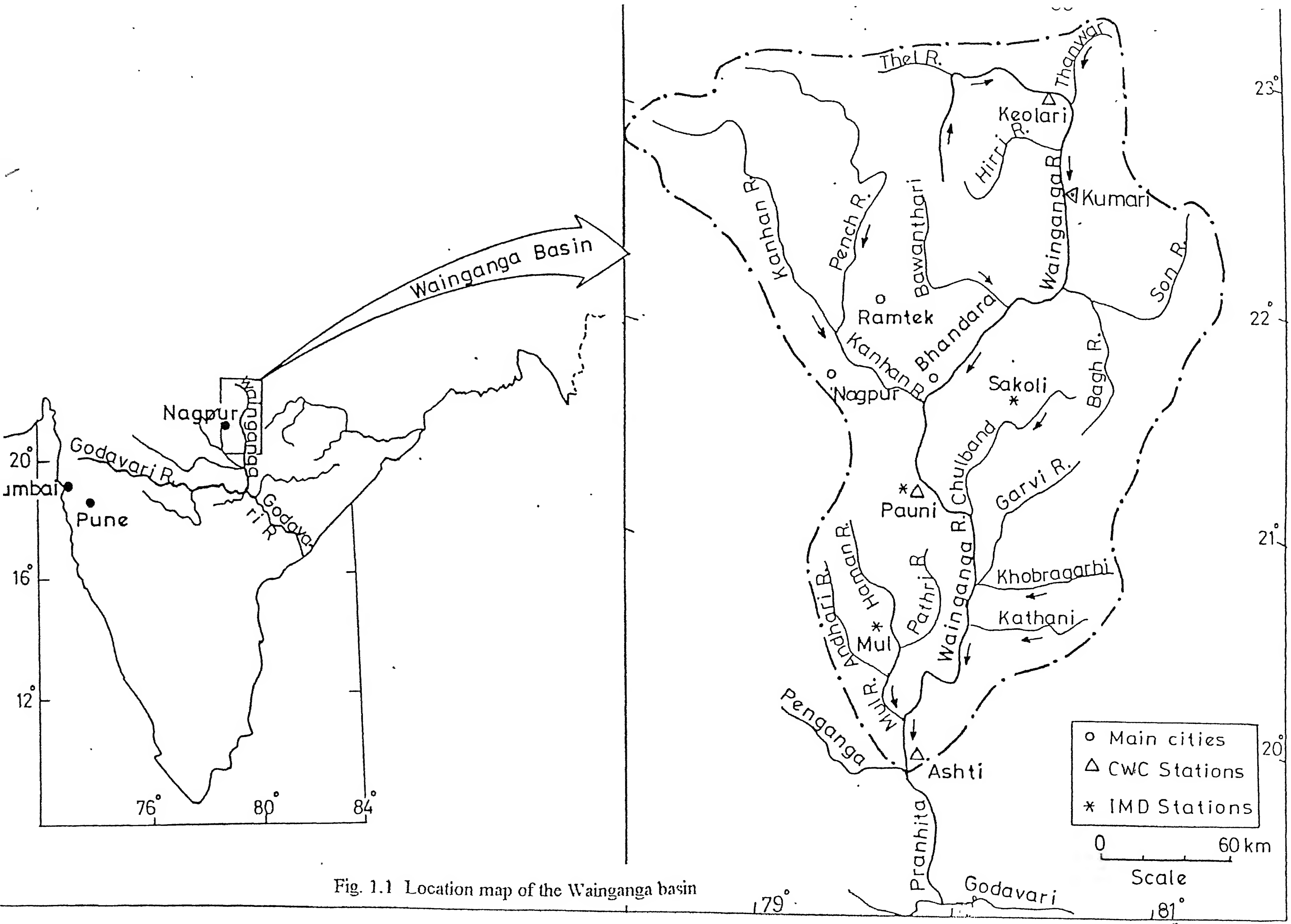


Fig. 1.1 Location map of the Wainganga basin

### 1.2 Geology of the Wainganga Basin

The Wainganga basin is comprised of varied rock formations ranging from the oldest Precambrian rocks to recent alluvial soils as shown in the geological map of the Wainganga basin in Fig. 1.2. table 1.1 presents generalized stratigraphy of the Wainganga basin

**Table 1.1 Stratigraphical Scale of the Geology of the Wainganga basin**

| Group | Age (million years) | Thickness (m) | Lithology |
|---|---|---|---|
| --------- | Recent | 10 | Alluvial soil |
| --------- | Pleistocene (2) | - | Laterite |
| Deccan Trap | Upper Cretaceous Eocene | 45 | Basalt |
| --------- | Upper Cretaceous(98) | 15 | Lameta Formation (conglomerate, sandstone, limestone, clay) |
| Gondwana Supergroup | Permian (258) | 168 | Kamthi Formation (sandstone, ferrugeneous sandstone) |
| Gondwana supergroup | Upper Carboniferous (320) | 20 | Talchir formation (sandstone and shale) |
| Vindhyan supergroup | Upper proterozoic (590) | - | Sandsone,shale and dolomite |
| Sakoli group | Middle Proterozoic(1545) | - | Mica-schist, phyllite and slate |
| Precambrian | Archean(2500-4000) | - | Granite and granite gneisses |

(Source: Harland et. al., 1982; Gwalani et. al., 1989).

The oldest Precambrian rocks (granite and granite gneisses) occupy the largest area in the southern and central portion of the Wainganga basin (Fig. 1.2). The rocks are overlain by hornblende schist, mica schist, quartzite, phyllites intruded by concordant basic and ultrabasic bodies.

The overlain rocks are correlated with Sakoli group exposed at the southern part of the point of confluence of the Kanhan river to Wainganga river. The geological map of the basin reveals that the northern, eastern and north-eastern parts are dominated by the Deccan traps whereas the Gondwana super groups are extensively exposed at SSW of the basin near Kamptee and Umrer locations in the Nagpur district. Isolated exposures of laterite capping and Deccan trap flows are exposed near to Seoni. The alluvium is mainly

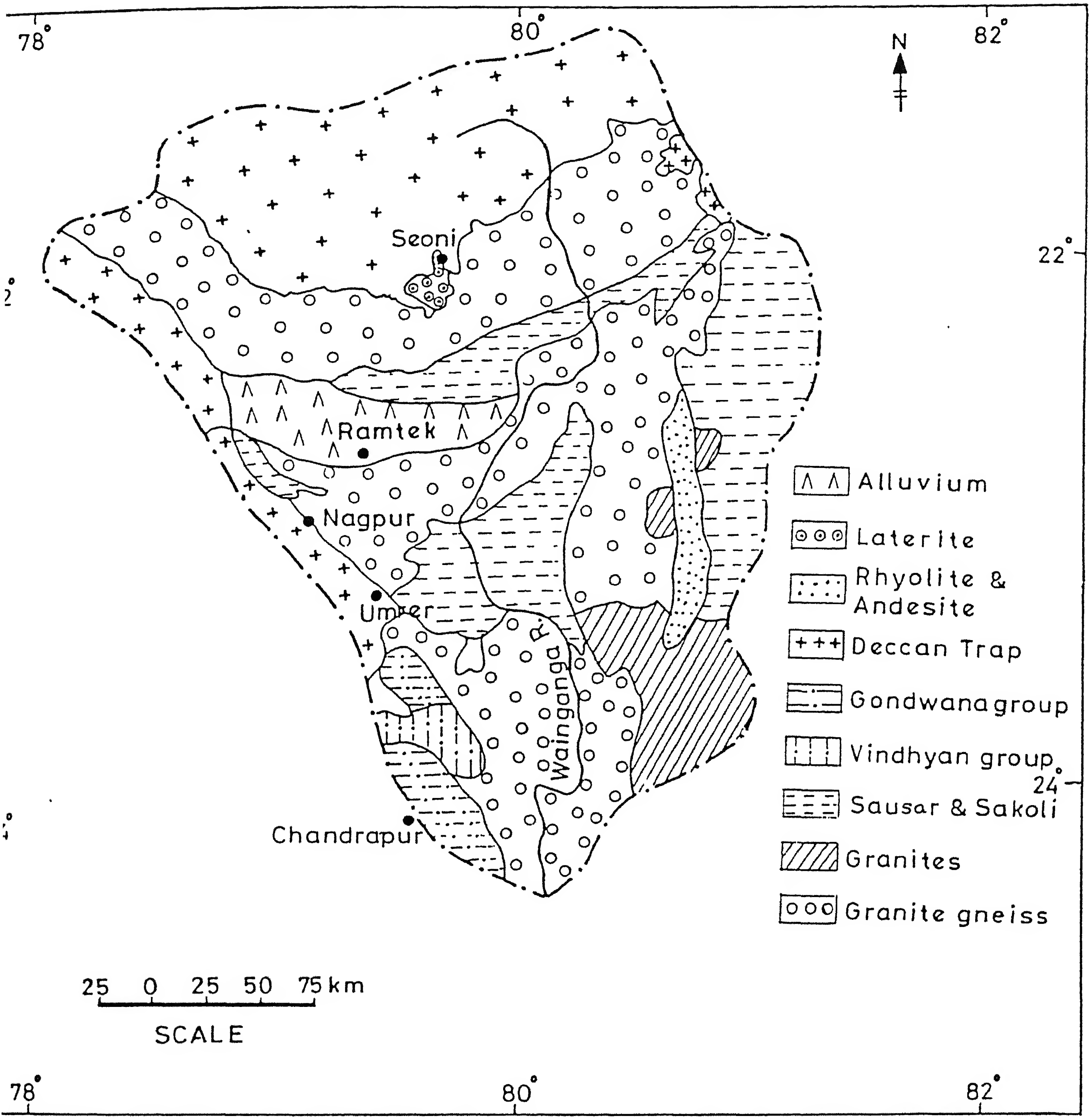


Fig. 1.2 Geological map of the Wainganga basin

restricted to the flood plains of the Wainganga river and its tributaries, a rather wide patch of alluvium is spread near Ramtek.

### 1.3 Drainage and Topography

The Wainganga river is joined by various tributaries at all offset points along the course of the river. The major tributaries joining the left bank of the Wainganga river are Thel, Thanwar, Bagh, Chulband and Garvi, Khobragarhi river and those joining the right bank are Hirri. Bawanthari, Kanhan and Mul rivers

The Wainganga basin encompasses the by Satpura ranges and Mahadeo Hills in the northern part forming the boundary of Madhya Pradesh and Maharashtra state The average elevation of the satpura ranges is 625 m above M.S.L The north-western portion of the basin is covered by a large number of high elevated hills with an average elevation 750 m above M.S.L. The southern portion of the basin has very few hills of small elevation of 260 m above M.S.L. The south and south-western portion of the basin is dominated by denudational hills, dissected pediments and pediplains.

### 1.4 Climatic Conditions

The Wainganga basin experiences the tropical climatic conditions. The monthly variation in the rainfall in the basin at Sakoli, Pauni and Mul is presented in the Fig 1.3 The average monthly rainfall at all stations ranges between 630 mm and 650 mm with maximum monthly rainfall in the month of August. In the month of January, the mean temperature in the basin lies between $15^{o}$-$25^{o}$. In the month of April, the temperature is $30^{o}$ or more. The atmospheric pressure in the basin in the month of January, April, July and October is in the range of 1018-1016, 1008-1010,1002-1000 and 1011-1013 milibar respectively. The wind direction in the month of January is Western and south-western

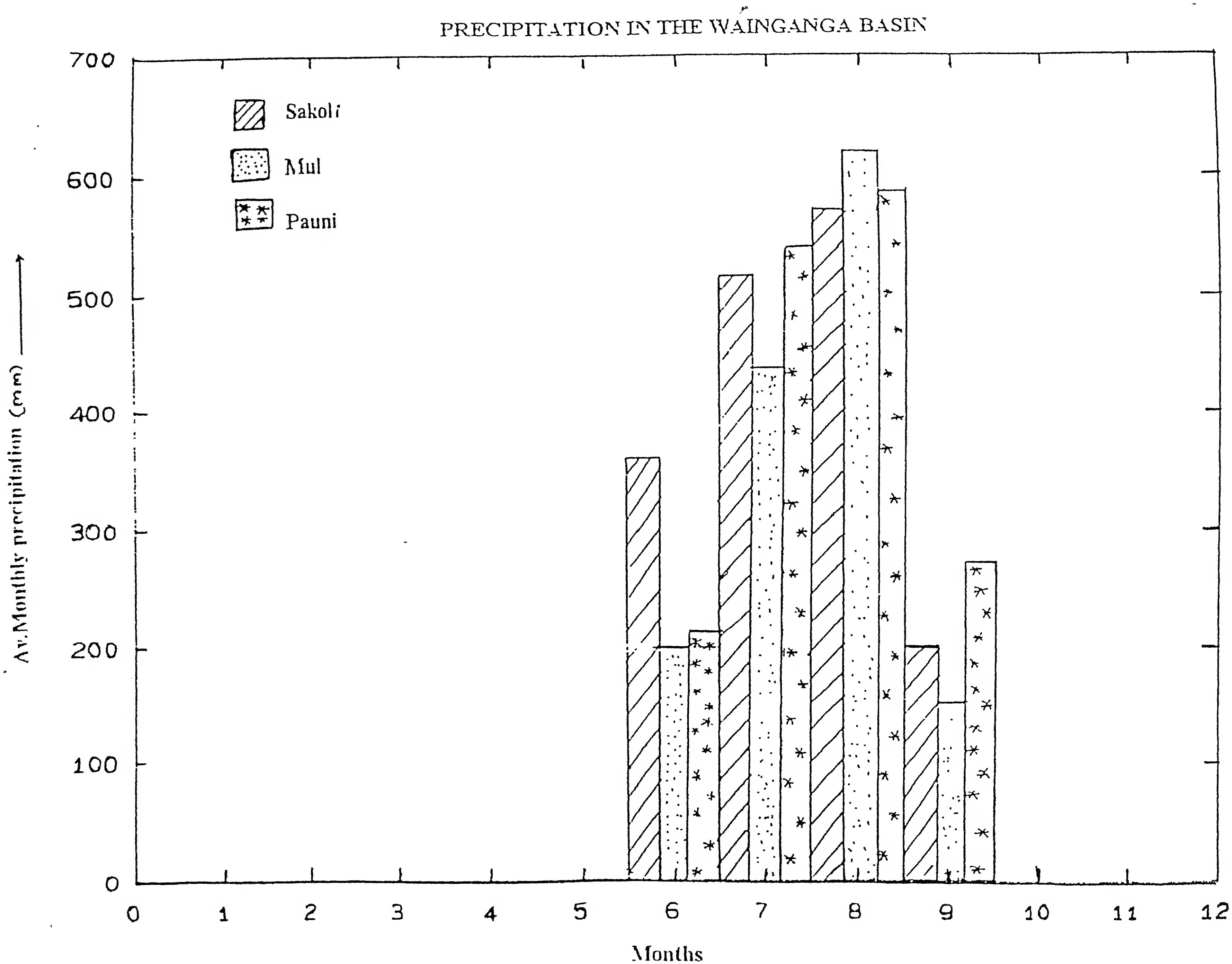


Fig. 1.3 The rainfall variation in the Wainganga basin.

and in the month of July the same is in Eastern and North eastern direction. Table 1.2 summarizes the climatic conditions in the Wainganga basin.

**Table 1.2 The climatic conditions of the Wainganga basin.**

| Parameters | February-May | June-September | October-January |
|---|---|---|---|
| Rainfall | < 50 mm | 630-650 mm | < 50 |
| Temperature | 30-32$^{o}$C | 25-27$^{o}$C | 15-20$^{o}$C |
| Pressure (mulibar) | 1008 | 1000-1002 | 1018-1011 |
| Wind direction | NW-SE | SW-NE | E-W |

## 1.5 Major Objectives

The major objectives of the present work are as follows·

i Analysis of drainage network characteristics

ii Mapping and interpretation of fluvial geomorphological features aided by remote sensing data.

iii Measurement and interpretation of channel morphological parameters

iv. Analysis of hydrological characteristics of the Wainganga river.

v. Analysis of sediment transport characteristics of the Wainganga river including hydraulic modelling.

vi. Comparison of the Wainganga river with other Indian rivers in terms of hydrologic and sediment transport characteristics.

## 1.6 Methodology and Plan of Work

The drainage map of river basin has been produced with the help of Survey of India toposheets of 1:250,000 (nos. 55J, 55K, 55N, 55O, 55P, 56M, 64B and 64D). The catchment characteristics and basin morphology have been studied with the help of drainage map in correlation with the available geological maps of the districts in the

Wainganga basin using the geological maps and field observations for ground truth verification.

The hydrological and sediment characteristics of the river were studied using the data obtained from Central Water Commisssion (CWC), Nagpur for the period 1988-1992 corresponding to the various CWC stations as shown in the Fig. 1.1. The rainfall data was collected from the Indian Meteorological department (IMD), Nagpur for Pauni, Sakoli and Mul meteorological stations (Fig. 1.1)

### 1.7 Organization of the Chapters

The present thesis is divided in four chapters. The first chapter introduces the location, the geology of the Wainganga basin and the thrust of the present work. The second chapter briefly describes the geomorphology of the Wainganga basin, catchment characteristics and channel morphology of the river In the third chapter, hydrological and sediment transport characteristics of the Wainganga river are presented In the concluding chapter, the hydrological and geomorphological characteristics of the Wainganga river are compared with other Indian rivers.

# CHAPTER 2

# CATCHMENT CHARACTERISTICS AND CHANNEL MORPHOLOGY

## 2.1 Introduction

The Wainganga basin is spread over Maharashtra state in the downstream reaches and Madhya Pradesh in the upstream reaches covering the major parts of Nagpur. Chandrapur, Garhchiroli, Bhandara, Balaghat, Seoni districts and minor part of Chhindwara, Durg districts The Wainganga river is approximately flowing at the mid of the basin traversing through Seoni, Balaghat, Bhandara and the border of Chandrapur and Garhchiroli districts. This chapter aims to provide the details of the geomorphological features, catchment characteristics and variation of channel forms in the Wainganga basin from its source to its confluence with the Godavari river.

## 2.2 Catchment characteristics

The total catchment area of the Wainganga basin is 51,000 sq. km and the total basin perimeter is 1175 km. The elongation index and the circularity ratio of the basin are 1.18 and 0 46 respectively. These values show that the Wainganga basin is far away from being the circular shape and is close to tear-shaped basin. The other catchment characteristics of the Wainganga basin are listed in the table below:

**Table 2.1 : Catchment characteristics of the Wainganga basin.**

| Stations (CWC sites) | Catchment area(km$^2$) | Channel length(km) |
|---|---|---|
| Keolari | 2970 | 128 |
| Kumhari | 8070 | 211 |
| Pauni | 35520 | 386 |
| Ashti | 50990 | 606 |

The catchment area and channel length have been measured from source up to particular site (CWC stations for hydrological measurements).

## 2.3 Drainage pattern and trend of streams

A detailed drainage map has been prepared for the entire Wainganga basin using toposheets of 1. 250,000 scale. A systematic study of drainage pattern and trend of the streams has been carried out and major variations have been interpreted in terms of lithological inhomogenities and structural features of the basin.

The Wainganga river is flowing in the north-south direction in its the upstream reaches and then it takes a sharp turn to flow NE-SW and then to NW-SE Further, it flows southward in its most downstream portion before joining Godavari through the Pranhita river..

The most common drainage pattern encountered in the Wainganga basin is dendritic (Fig .2.1), a characteristic of hard rock terrain with uniform resistance of the rocks. However, there are distinct variations in the spacing of drainage which is essentially a reflection of lithological inhomogenities. For example, the extreme north eastern part of the basin has large drainage spacing than that of northern and north-western part of the basin. The north-eastern part is dominated by various types of rocks (limestone, sandstone, gneisses and Deccan traps) which reflects the inhomogeneity in the rock types whereas the northern and north-western parts are dominantly covered by massive Deccan

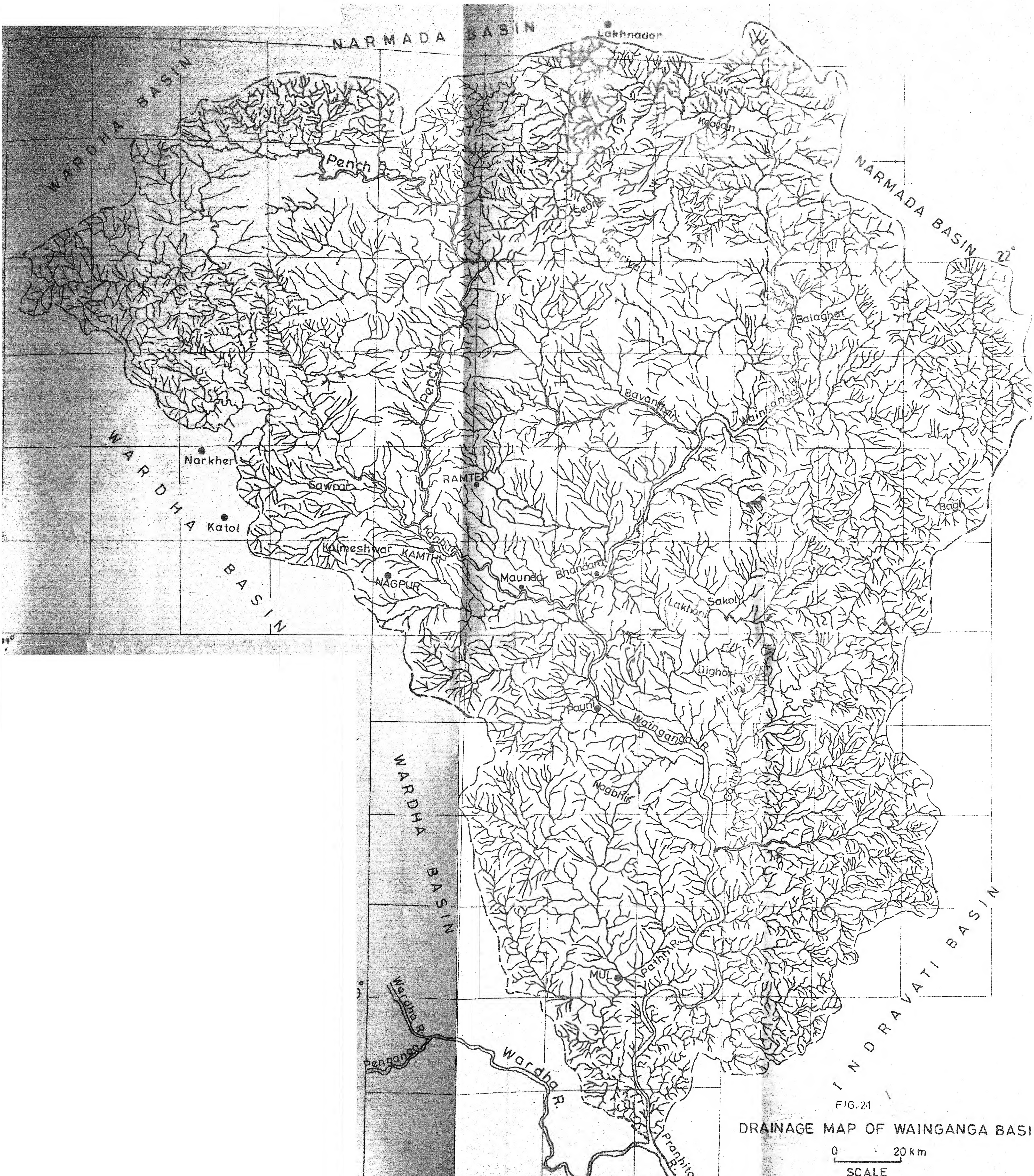


FIG. 2·1

DRAINAGE MAP OF WAINGANGA BASI

0 20 km
SCALE

traps The downward left portion of the basin near the Garhchiroli is covered with granites and exhibits large number of low spacing dendritic drainage.

The middle part of the basin (Ramtek and Bhandara region) exhibits parallel drainage pattern trending NW-SE. This drainage pattern seems to be controlled by pronounced fold dipping in south-east direction (Subbarao et al., 1980) The upstream reach of the Kanhan river shows rectangular drainage pattern. As will be demonstrated later through remote sensing investigations, this marks a major structural control Another interesting observation is that all the major tributaries of the Wainganga river joining the right bank flowing in NW-SE direction where as all tributaries at the left bank are joining at right angles and flow in east-west direction. An earlier study in parts of the Wainganga basin (Subbarao et. al., 1980) has indicated a major structural control in the drainage basin and has delineated a number of structural features using aerial photographs and Landsat imageries.

## 2.4 Interpretation of Geomorphological Features and Engineering Structures Aided by Remote Sensing Data

Remote sensing is an effective and powerful tool for detection and identification of earth resources and dynamic changes occurring on the earth's surface and it is frequently used for comparing channel conditions in spatial and time domain. River morphology is studied by remote sensing for rectification and stabilization work because all geomorphic features such channel bar, point bar, flood plains, terraces and paleochannels can be effectively studied using satellite remote sensing data.

### *2.4.1 Data used and methodology*

The IRS-1B LISS I ( spatial resolution of 72.5 m and swath width of 148 km) remote sensing data (path-26 and row-53) has been used for the study. Two coverages

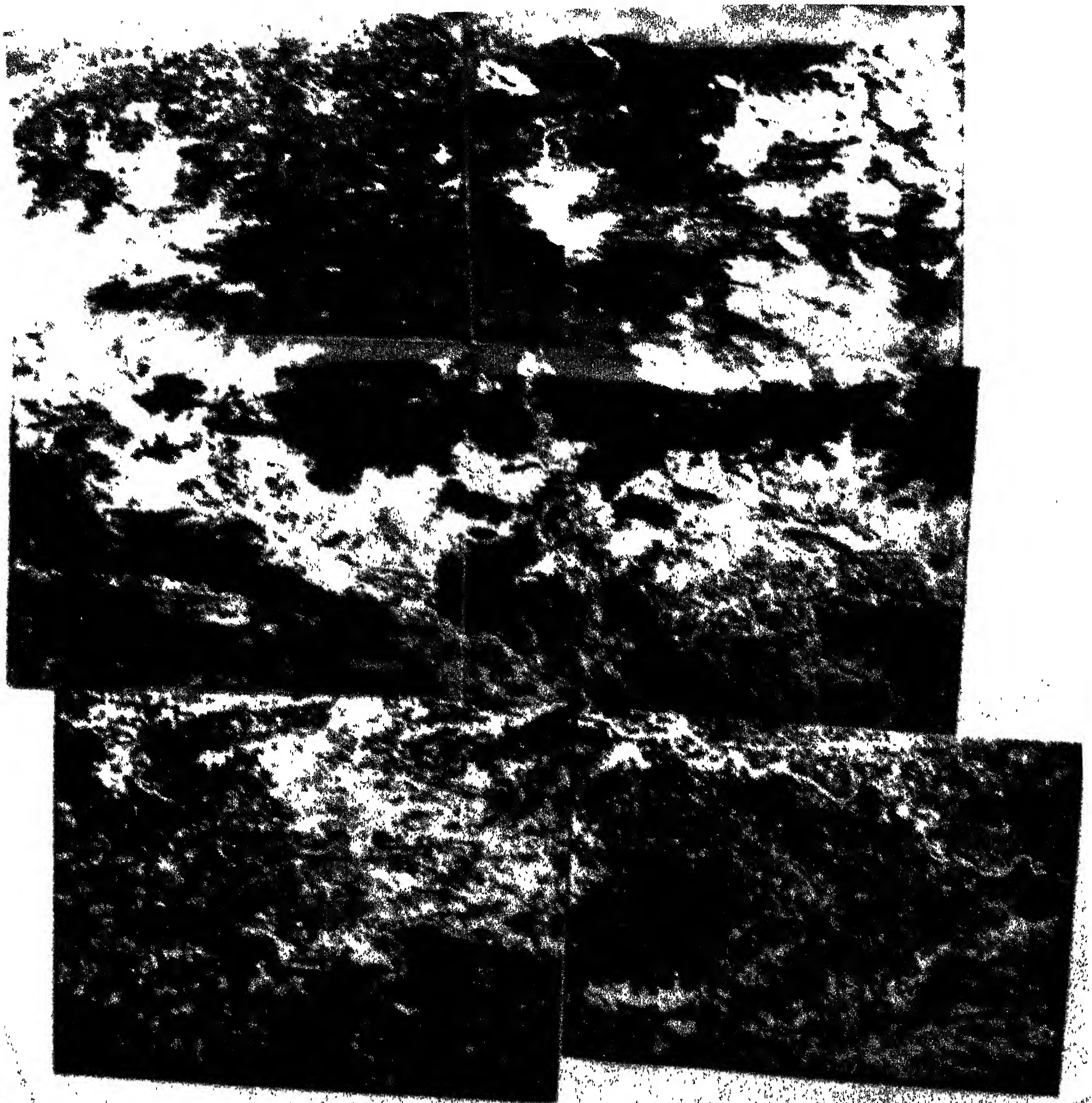

Fig. 2.2 Mosaic of the remote sensing images

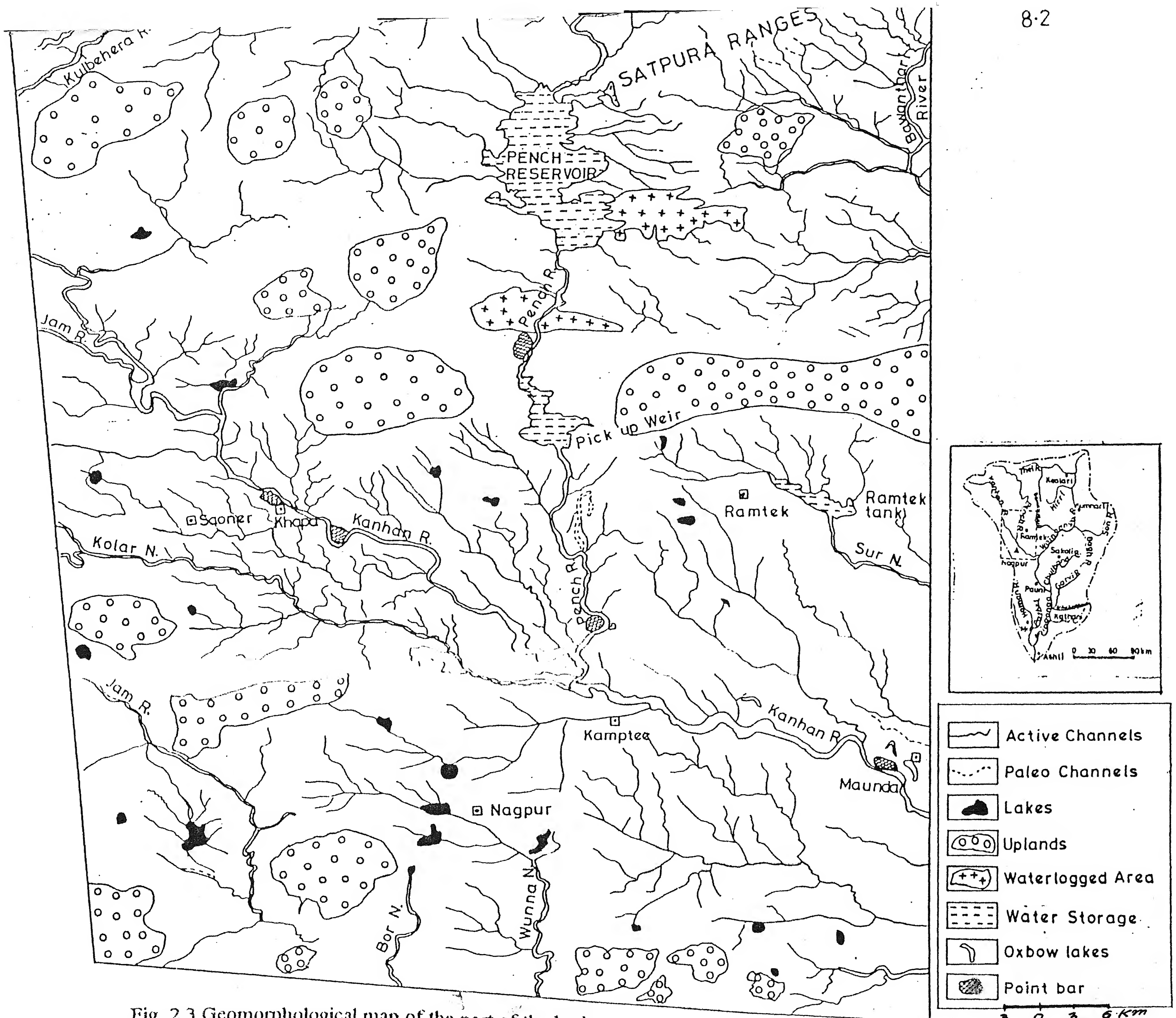


Fig. 2.3 Geomorphological map of the part of the basin

were obtained for the study area corresponding to pre-monsoon ( May 29,1993) and post-monsoon (December 13, 1993) period. This data covers major part of Nagpur district including Kanhan river, a major tributary of the Wainganga river (Fig. 2.1) The total area covered by the image corresponds to toposheet nos. 55O, 55K (1:250,000).

False Color Composites (FCC) were generated for different sub-scenes of the image by assigning red color to first band, green color to second band and blue color to third band. These were photographed from image display unit and a mosaic was prepared (Fig. 2.2) and then the geomorphological mapping was carried out followed by ground truth verification through maps and field observations.

*2.4.2 Geomorphological Features and Engineering Structures*

Figure 2.3 shows the geomorphological map produced with the help of digitally processed remote sensing data. The major rivers delineated on the geomorphological map include Bawanthari, Wunna, Bor Nadi, Kolar Nadi, Sur Nadi, Jam Nadi, Sur Nadi and Kulbehra Nadi. The area shown in the geomorphological map has more or less broken and mountainous topography of granite gneiss and saucer group rocks and hence the fluvial activities are very dull because of the controlled topography and lithology. The streams in the Wainganga basin are controlled by geological structures (Fig. 2.4). The figure shows the fault trending in SW- NE direction forcing Kanhan river to flow in the same direction for considerable distance. Apart from active channels, the other fluvial geomporphological features present in the Wainganga basin are as follows:

(i) Point bars: Point bars are the most characteristics features of meandering rivers particularly form on the convex sides of meanders. Along the river, the point bars are confined in the reaches between Bhandara and Pauni (Fig. 2.5 a) whereas at Ashti no point bar formation is observed and hard rocks are exposed in the river valley (Fig. 2.5 b).

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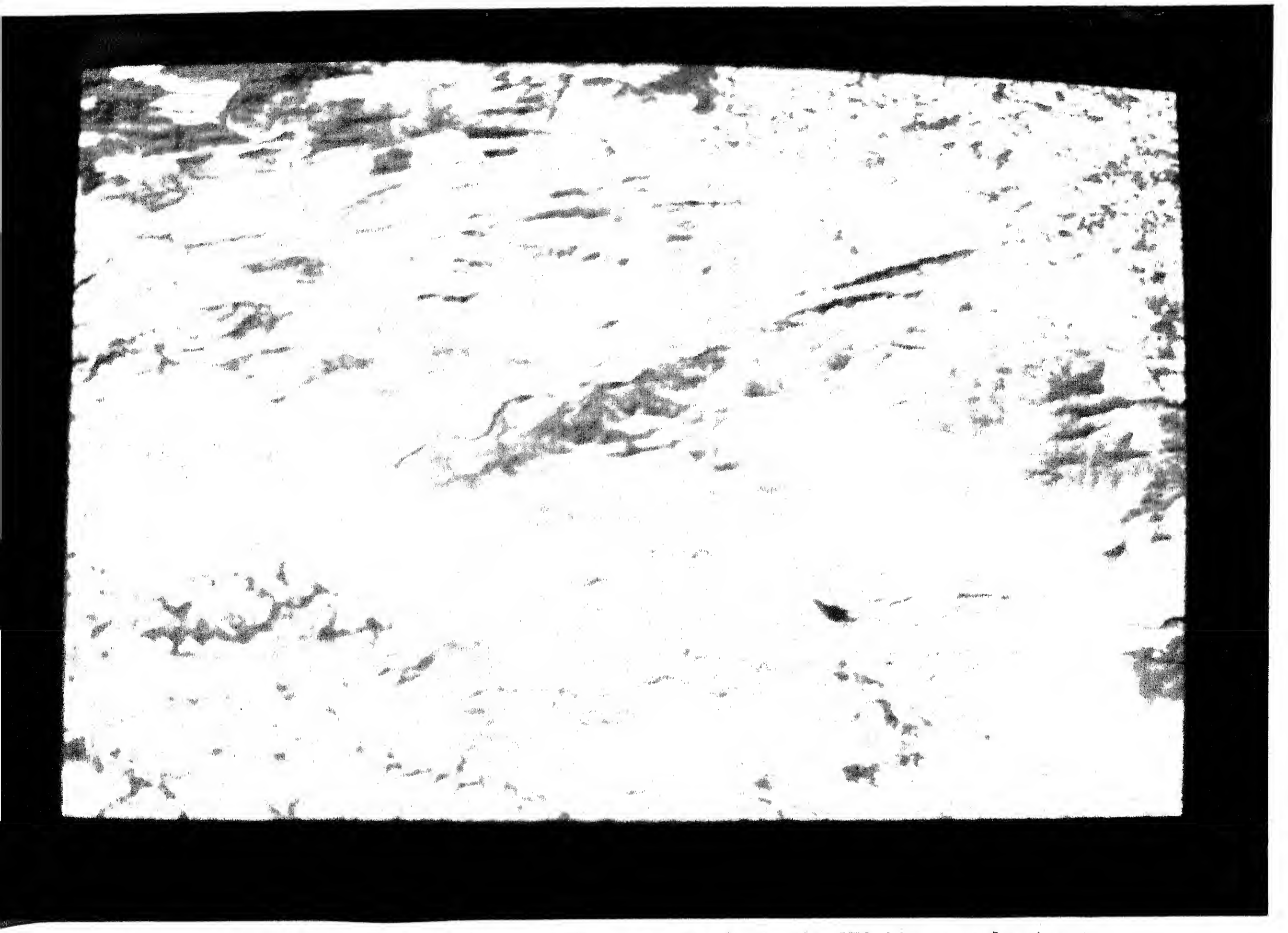

Fig.2·4 **Remote Sensing Image Showing Fault in the Wainganga basin**

**Fig. 2.5 (a) Point Bar at Pauni**

**Fig. 2.5 (b). Mid-channel exposure of hard rocks at Ashti**

**Fig. 2.6 (a) Channel bar and meander at Pauni**

**Fig. 2.6 (b). Channel bar at Bhandara**

At Pauni station the reach is dominated by alluvial cover which only leads to the incising of right bank and formation point bar at the left bank (Fig. 2 6 a).

(ii) Channel bars. Channel bars formed by the deposition of the bed load of the rivers are frequently observed at Bhandara and Pauni station (Fig 2.6 b) whereas Ashti station is devoid of any channel bar formation The satellite image covering the part of the Kanhan river also shows significant channel bar formation in the downstream reaches of the river before it joins the Wainganga river.

(iii) Paleochannels In general, very few channels are observed in the Wainganga basin suggesting that channels are fairly stable in this region Local information reveals the existence of few paleochannels near the Pauni station reported to be about 150 years old

(iv) Floodplain features. The Wainganga river has very wide flood plains (up to 5 km) in the downstream reaches. At Bhandara and Pauni , the point bars are graded into the flood plains because of the flat topography in the area. on the other hand, at Ashti station ,deep cut river banks are expose the bed rocks indicating relatively thinner flood plains deposits However, the flood plain width usually increases downstream. The commonly observed flood plain features include ox-bow lakes and swamps

Swamps are low lying areas of shallow water table. In Wainganga basin, few swamps are observed in the vicinity of the Pench reservoir which may have been produced by the seepage of water from the reservoir (Fig. 2.3).

Channel reaches abandoned through neck cutoff have been converted into the ox-bow lakes at some locations These lake have been completely isolated from the present river with further migration of stream course. The abandoned route has been filled with silt and clay materials in due course of time. The ox-bow lakes are confined to

downstream reaches of the Wainganga and Kanhan river and suggest limited local movements of river channels through meander cutoffs.

(v) Uplands: These are outcrops produced by volcanic eruptions ( Deccan Traps ) as observed in the north-western and south-western part of the basin, some uplands in the eastern part of the basin consist of Sakoli and Saucer group of rocks. These cone shaped geomorphic features are delineated from remote sensing image (Fig. 2.2) with help of toposheets The uplands are spread throughout the Wainganga basin.

(vi) Lakes. A number of small depressions filled up with water are observed in the Wainganga basin because of the undulating topography of the basin The lakes are particularly frequent in Bhandara region All the lakes are located in the vicinity of active channel suggesting regular input of water and sediments

A number of engineering structures are located in the Wainganga basin. A multipurpose reservoir is located at Totladoh on the Pench river. a tributary of Kanhan river, and is popularly Known as "Pench Project" It provides 1600 megawatts of power, drinking water and make irrigation of 24000 hectares of land. It is observed from the satellite image (Fig. 2.2) that the area surrounding to the Pench project is surrounded by Satpura Ranges at north-eastern and south-eastern side. Apart from these ranges, the reservoir is fenced with broken and rugged topography because of which bringing out of canals from the reservoir is an extremely difficult and expensive work. Therefore a pick up weir has been constructed ( Fig. 2.2 ) at about 25 km downstream to the reservoir, which is confined by parts of Satpura ranges to its left and right sides. The land cover downstream of the pick weir is only agricultural land e.g. orange orchards and paddy fields growing on alluvial soil and black cotton soil. Another interesting feature in this area is Ramtek tank constructed on the Sur river, another tributary of the Wainganga

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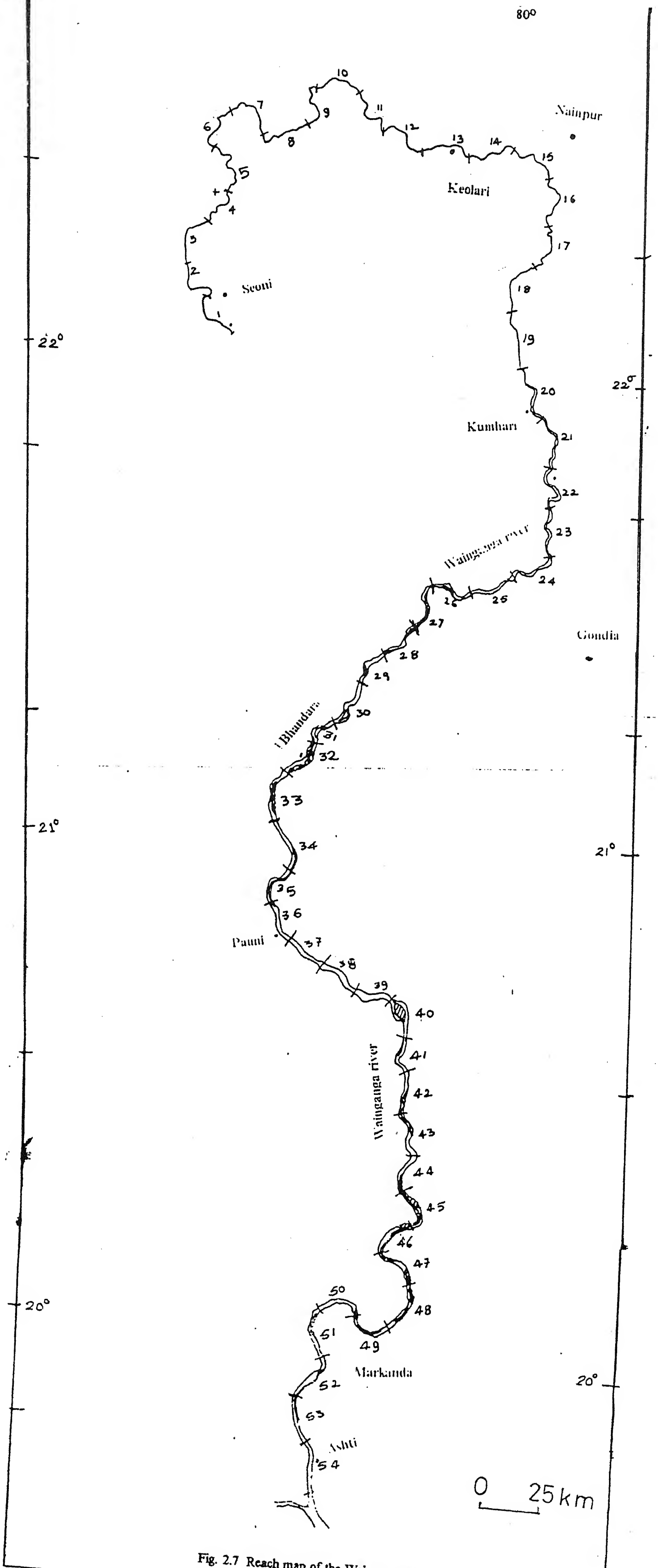


Fig. 2.7 Reach map of the Wainganga river

river. Ramtek tank consisting of the area of 12.86 sq. km provides water to Ramtek town and surrounding agricultural land.

## 2.5 Channel Morphology

Most of the channel size and morphological parameters of the Wainganga river have been derived from morphological data of CWC and topographic maps (1 250,000). The channel morphology is described in the terms of planforms, cross-sections and longitudinal profile of the river.

### *2.5.1 Sinuosity and Braid-channel Ratio*

Channel planform represents a mode of channel form adjustment in the horizontal plane which is additional but linked with transverse and lengthwise mode. It influences resistance to flow and can be regarded as an alternative to slope adjustments.

The sinuosity of any river channel is defined as valley length over reach length i.e. $S = Lcmax / Lr$ (Friend & Sinha, 1993), where Lcmax is mid channel length of widest channel in a specific reach and Lr is the length of river reach.

The braid-channel ratio (B) developed by Richards (1982) and modified by Friend and Sinha (1993) is expressed as,

B = Lctot /Lcmax

where Lctot = sum of the mid channel lengths of all segments of primary channels in a reach. Lcmax = mid channel length of the widest channel through the reach

The sinuosity and braid-channel ratio (B.C.R) measurements were carried out for the Wainganga river channel by taking a reach length of 10 km, (Fig. 2.7) using 1 : 250,000 toposheets (1980-81). The results are presented in the table 2.2.

Table: 2.2 Sinuosity and braid channel ratio

| Reach No. | Sinuosity | BCR | Reach No. | Sinuosity | BCR |
|---|---|---|---|---|---|
| 1 | 1.25 | - | 28 | 1.03 | 1 08 |
| 2 | 1.48 | - | 29 | 1.14 | 1 08 |
| 3 | 1.08 | - | 30 | 1.00 | 1.05 |
| 4 | 1.08 | - | 31 | 1.03 | 1.33 |
| 5 | 1.38 | - | 32 | 1.00 | 1.10 |
| 6 | 1 48 | - | 33 | 1 03 | 1.10 |
| 7 | 1.33 | - | 34 | 1.00 | 1.00 |
| 8 | 1.18 | | 35 | 1.18 | 1.00 |
| 9 | 1.54 | - | 36 | 1.14 | 1.00 |
| 10 | 1.18 | - | 37 | 1.00 | 1.00 |
| 11 | 1.33 | - | 38 | 1.00 | 1 00 |
| 12 | 1.33 | - | 39 | 1.05 | 1.00 |
| 13 | 1 14 | - | 40 | 1 05 | 1.25 |
| 14 | 1.18 | - | 41 | 1.33 | 1 00 |
| 15 | 1.25 | - | 42 | 1.00 | 1.25 |
| 16 | 1.18 | - | 43 | 1.05 | 1.13 |
| 17 | 1.33 | - | 44 | 1 08 | 1.08 |
| 18 | 1 14 | - | 45 | 1.25 | 1.25 |
| 19 | 1.09 | - | 46 | 1.05 | 1.25 |
| 20 | 1.08 | - | 47 | 1.05 | 1.10 |
| 21 | 1.21 | - | 48 | 1 00 | 1.10 |
| 22 | 1.14 | - | 49 | 1.25 | 1.10 |
| 23 | 1.08 | - | 50 | 1 18 | 1.10 |
| 24 | 1.14 | - | 51 | 1.00 | 1 00 |
| 25 | 1.08 | - | 52 | 1 00 | 1 00 |
| 26 | 1.33 | - | 53 | 1.00 | 1 00 |
| 27 | 1.20 | 1.25 | 54 | 1.00 | 1 00 |

The sinuosity of the upstream reaches (reach no. 1 to reach no. 18) is higher than that of the downstream reaches. The absence of the long straight reaches and presence of the higher sinuosity is regarded as evidence of an inherent tendency in natural streams to meander. The reaches for which sinuosity is unity reflect that those reaches are steep and confined by hard rocks. For the Wainganga river, the most of the reaches have sinuosity between 1 and 1.3 reflecting the moderate slope of channel bed and incising of the river banks (Schumm, 1965).

The BCR exceeds unity for from reach no. 27 to 33 and reach no. 40 to 50, thereby indicating the deposition of sediment load in these reaches of the Wainganga river This is also confirmed through field observations at Bhandara (Fig. 2.5a ). Further, the reach no. 40 has a large channel bar which is reflected in the BCR value of greater than unity. The downstream reaches (51 to 54) do not show any formation of channel bars.

A plot (Fig. 2 8) is generated between sinuosity and braid - channel ratio shows that BCR is increasing at unity of sinuosity whereas the sinuosity is increasing at unity of B.C.R It shows that there is certain compromise between sinuosity and braid channel ratio for deposition of sediment and incising of the banks It shows that channel bars are not generated at the reaches of high sinuosity and braids are frequently formed along the straight reaches of the Wainganga river The average values of sinuosity and B.C.R are 1.04 and 1.01 which lower than that of 1.50 ( Leopold and Wolman, 1957) and 1.5 (Schumm, 1965) respectively. Hence it can be concluded that the Wainganga river is mostly straight and single channel river.

*2.5.2 Form Ratio and Cross-section Along the River*

The river cross-section is represented by form ratios expressed as the ratio of width (w) of channel over depth (d) of the channel.

Form ratio = w/ d

Where w = width of a channel and d = depth of channel.

**Table 2.3: The cross-sectional changes and form ratio along the channel**

| Station | w(m) | d(m) | c/s Area(sq. m) | Form ratio(F) |
|---|---|---|---|---|
| Keolari | 145 | 14 | 1380 | 10.357 |
| kumhari | 309 | 16 | 3560 | 19.313 |

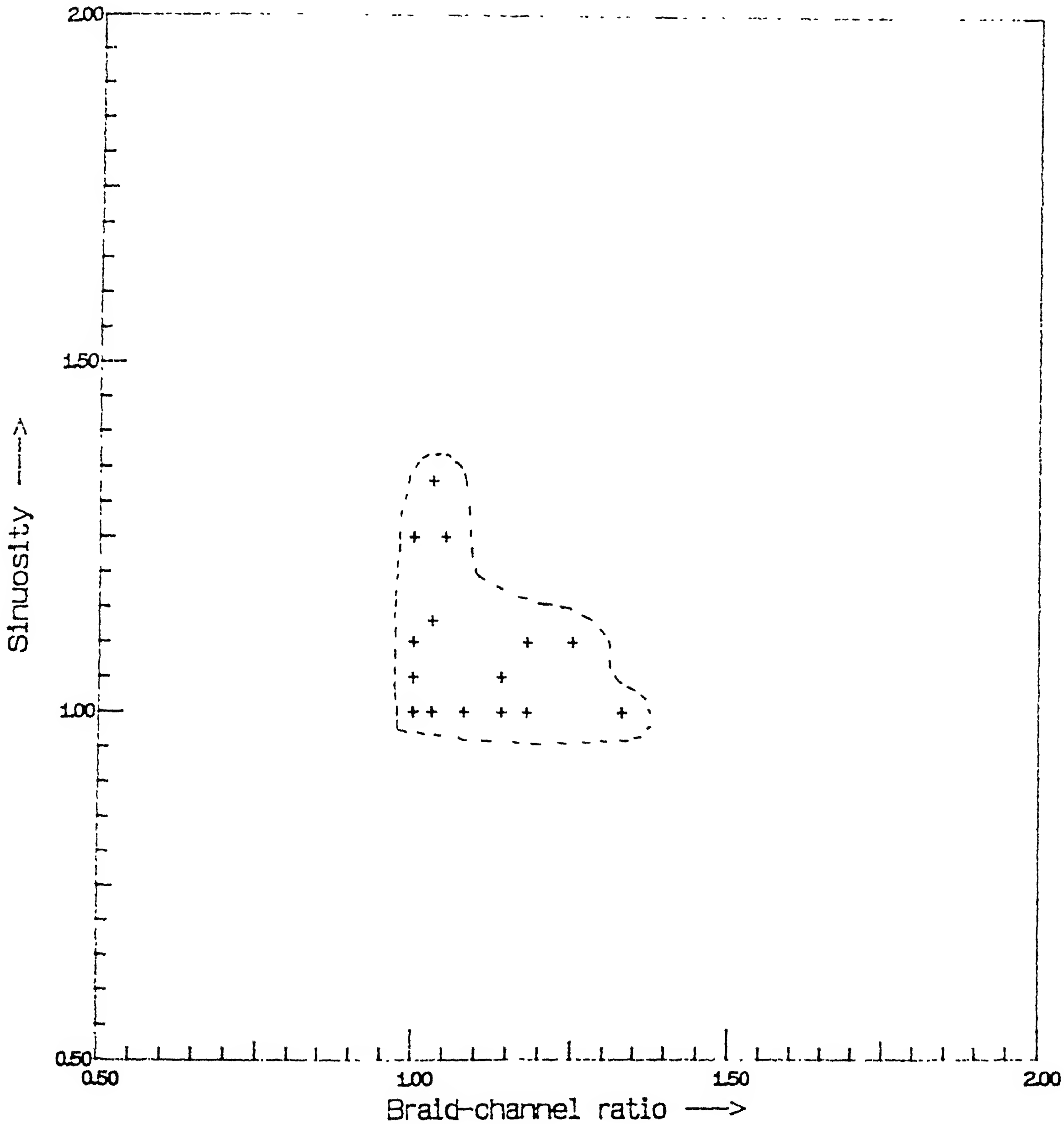


Fig. 2.8 : Plot of sinuosity versus Braid channel ratio of the Wainganga river

| | | | | |
|---|---|---|---|---|
| Pauni | 690 | 12.725 | 6370 | 54.224 |
| Ashti | 780 | 11.58 | 6689 | 67.35 |

Table 2.3 shows that form ratio is gradually increasing from Keolari to Kumhari and Pauni to Ashti whereas there is a drastic changes in form ratio from Kumhari to Pauni These variations in the form ratio reflect the geometry of the cross-sections along the Wainganga river. An ideal view of the cross-sections at all CWC stations along the Wainganga river is shown in the Fig 2.9. It is observed from the figure that the cross-sections at upstream reaches are narrow and deep while those are shallow and wide in the downstream reaches.

### *2.5.3 Longitudinal Profile of the Wainganga river*

The longitudinal section of a river valley from its source to mouth is known as longitudinal profile. It is gradually formed due to the erosion and deposition along the course of the river. Longitudinal profile of the Wainganga river consist of four major segments and all four segments are differing from each other in respect of length and gradient ( Fig. 2.9). The profile shows the longitudinal gradient of the river is smoothly decreasing from Pipariya to Kumhari and from Pauni to Ashti whereas a drastic change in gradient is observed from Kumhari up to mouth ( table 2.4.)

**Table 2.4 Gradients of the river reaches**

| Reach | Valley length (km) | Gradient |
|---|---|---|
| Pipariya-Keolari | 128 | 1: 732 |
| Keolari-Kumhari | 83 | 1: 602 |
| Kumhari-Pauni | 175 | 1: 2663 |
| Pauni-Ashti | 220 | 1: 2688 |

The longitudinal profile tend to be concave upward but it is rarely smooth because there is sharp change in the gradients of reaches Keolari-Kumhari and Kumhari-Pauni. The upstream reaches i.e. Pipariya-Keolari and Keolari-Kumhari have nearly equal

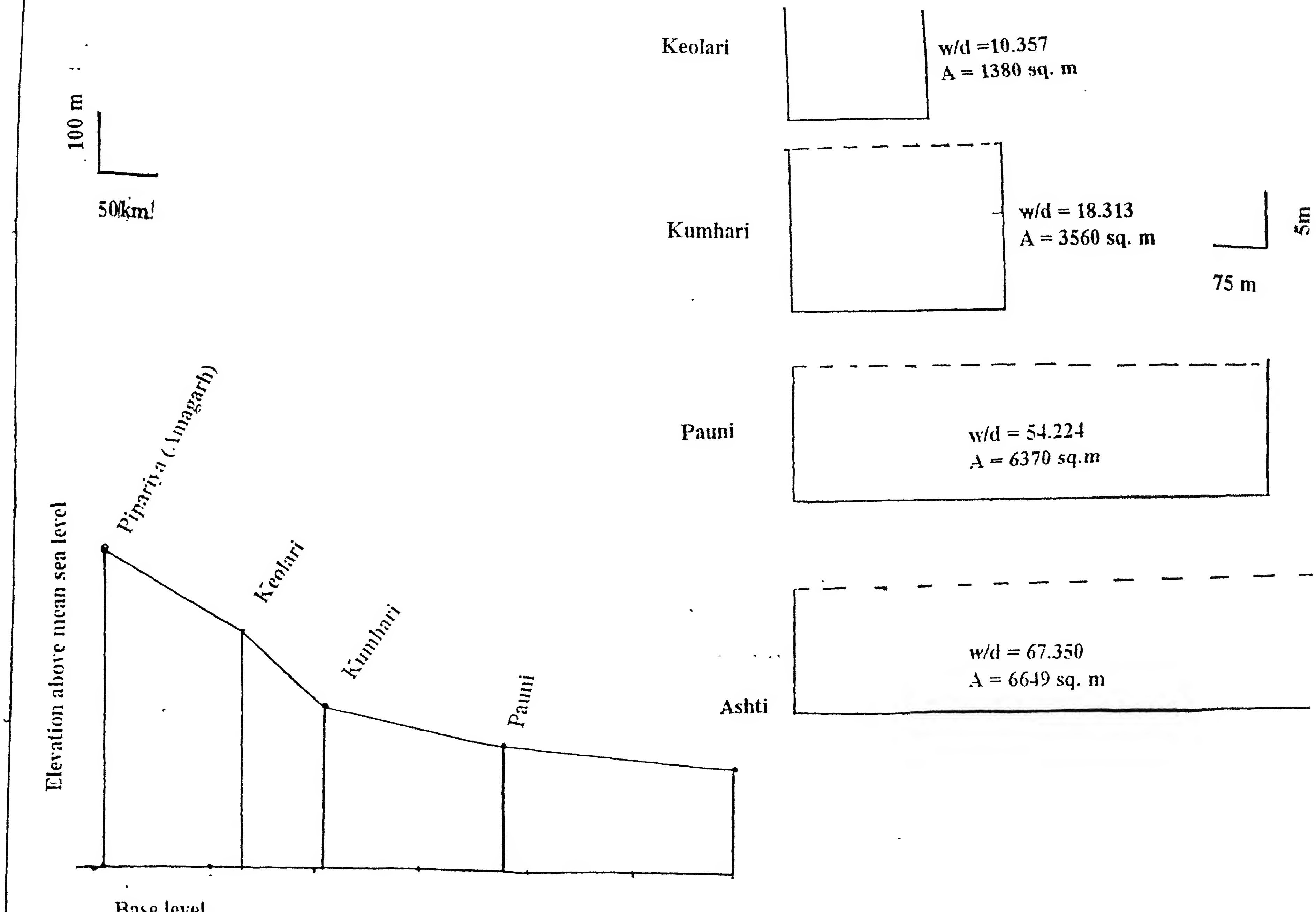


Fig. 2.9 : Longitudinal profile of the Wainganga river

gradients, similarly the downstream reaches Kumhari-Pauni and Pauni-Ashti have equal gradients. Hence it can observed from the figure and table that longitudinal profile of the Wainganga river is steep in the upstream part and flat in the downstream part

## 2.6 Discussion

The longitudinal profile shows that the upstream most reaches of the Wainganga river consist of high gradient. Therefore the generation of the channel bar is limited because of the high stream power Because of the steep topography in the upstream, the reaches are more sinuous than that of the downstream. The form ratio and channel gradient follow the compromising pattern because the higher gradient in the upstream reaches which scours the channel bed resulting narrow and deep cross-sections. Hence the cross-section and planform of the Wainganga river is controlled by gradients of river reaches.

# CHAPTER 3

# HYDROLOGY AND SEDIMENT TRANSPORT

## 3.1 Introduction

Alluvial river channels are self formed and their morphology results from the entrainment, transportation and deposition of the unconsolidated sedimentary materials of valley fills and flood plain deposits across which they flow. Alluvial channel forms are dependent on the environmental controls of hydrology and sediment transport. A river basin represent the most active component in hydrological cycle All the rivers of the world transport more than 90 % of the weathered material from the continents to the oceans Material so transported are recycled through the geological time at very slow rates ( Garrels et al., 1975). In this chapter, hydrological and sediment transport characteristics of the Wainganga river are presented Empirical relations are established which show variation in sediment concentration and water discharge.

## 3.2 Data Available

The hydrological data was collected from Central Water Commission (C.W.C.), Nagpur including water level, water discharge, peak discharge and sediment discharge for five years ( 1988-1992) corresponding to four stations namely Keolari, Kumhari, Pauni and Ashti ( Fig. 1.1 and table 3.1).

**Table 3.1: Hydrological data obtained from CWC**

| Station | Drainage Area | R.L.of Channel bed(m) | Discharge data Available | Sediment data Available |
|---|---|---|---|---|
| Keolari | 2970 sq. km | 425 000 | 1988-1992 | N A |
| Kumhari | 8070 sq km | 289.000 | 1988-1992 | NA |
| Pauni | 35520 sq km | 223.275 | 1988-1992 | 1988-1992 |
| Ashti | 50990 sq km | 141.420 | 1988-1992 | 1988-1992 |

All these data are recorded by CWC on daily basis; however, in the present work only monthly averages of this data are analyzed. The sediment data are based on suspended load sampling and the size grades distinguished are those defined by CWC (circular on Sampling of fluvial sediment , Bed material and Water Samples, Unpublished), as coarse (> 0.2 mm), medium (0.2-0.075 mm) and fine (<0.075 mm)

Daily precipitation data was obtained from the Indian Meteorological department (IMD), Nagpur for five years (1988-92) at meteorological stations Sakoli, Pauni and Mul in the Wainganga basin (Fig. 1.1). The data is available for the monsoon months (June-September) only; no precipitation data is recorded during non-monsoon period which, in the present work, is taken as negligible. Hence, average monthly and annual precipitation have been computed on the basis of monsoonal precipitation only.

### 3.3 Hydrological Characteristics of the Wainganga river

From the data available from CWC, the following hydrological parameters are derived for each station:-

a) Monthly average discharge: One discharge measurement ($m^3/s$) per day, averaged for the whole month.

b) Annual average discharge: Average of daily discharges ($m^3/s$) for the whole year.

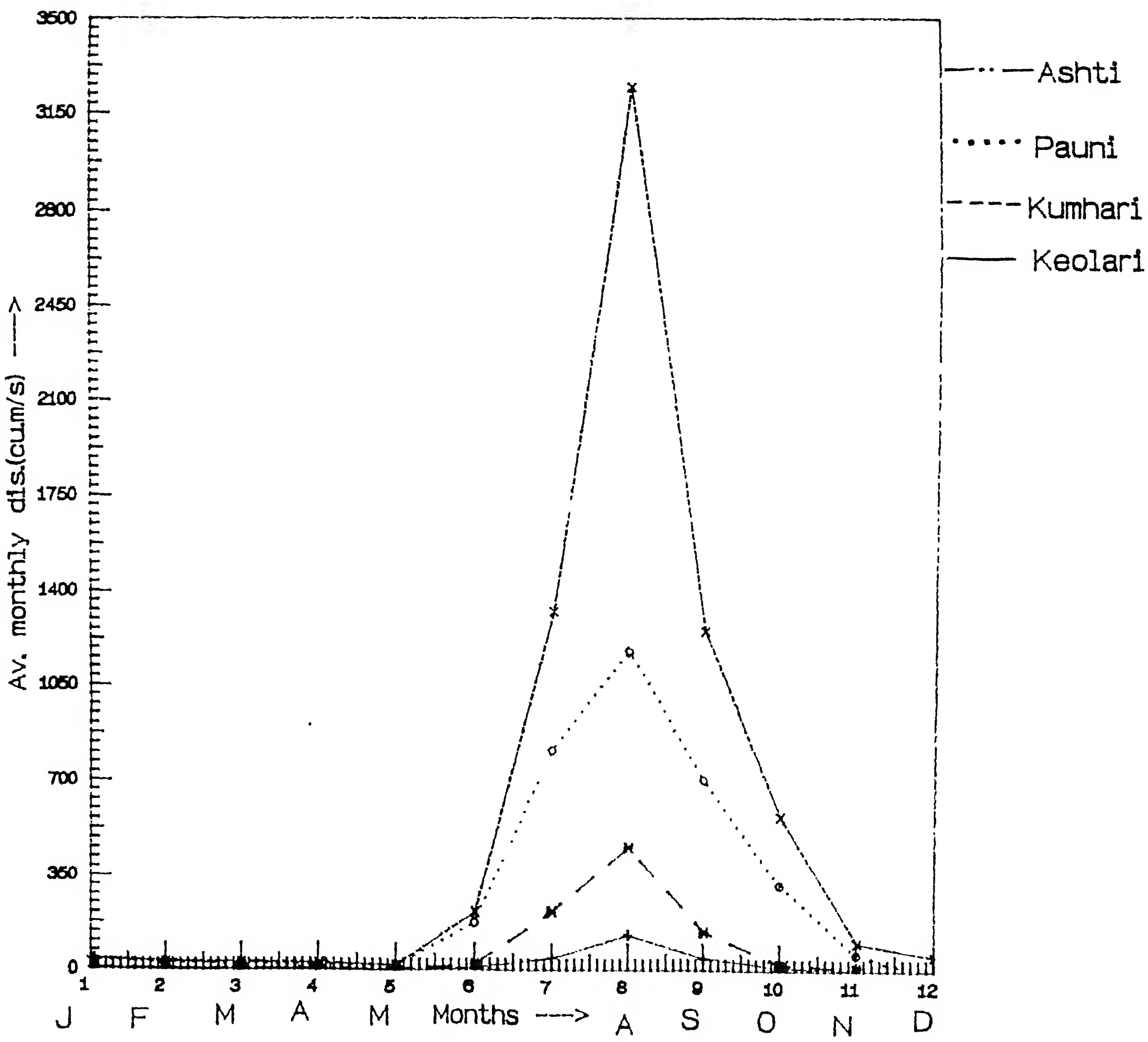


Fig. 3.1 The average monthly variation of discharges at CWC stations

c) Peak discharge: Maximum discharge ($m^3/s$) observed on a particular day during the whole year.

d) Bankfull discharge: The discharge corresponding to danger level obtained from the flood hydrograph of discharge against water level.

**Table 3.2: Average monthly discharge at CWC stations.**

| Stations Months | Keolari | Kumhari | Pauni | Ashti |
|---|---|---|---|---|
| January | 1.88 | 1.598 | 34.44 | 37.52 |
| February | 0.826 | 1.054 | 24.92 | 27.15 |
| March | 0.306 | 0 750 | 20.83 | 25 78 |
| April | 0 | 0.615 | 13.46 | 22.48 |
| May | 0 | 0.325 | 14.51 | 16 09 |
| June | 6.59 | 18.683 | 170 49 | 210 12 |
| July | 42.275 | 212.385 | 811.2 | 1324 |
| August | 129.828 | 454.875 | 1178.66 | 3241.83 |
| September | 42.04 | 138.163 | 702.17 | 1254 43 |
| October | 10.543 | 19.737 | 311.05 | 567 73 |
| November | 2.657 | 6.268 | 57.00 | 100 62 |
| December | 1.515 | 2.463 | 25.26 | 38.00 |

Table 3.2 and Fig. 3.1 shows the variation of the average monthly discharge throughout the year corresponding to Keolari, Kumhari, Pauni and Ashti stations. It is observed from the plot that the Wainganga river is truly monsoonal river, discharge approaching to zero non-monsoon months The unimodal distribution is observed at all stations along the Wainganga river and peak discharges occurred in the month of August only. It is also observed from figure that there is vast difference in water discharges of upstream stations and downstream stations reflecting the huge feeding of discharge by confluencing tributaries in the downward direction.

Table 3.3 Hydrological characteristics of the Wainganga river

| Stations | Av.annual discharge ( $m^3/s$) | Av.annual runoff (M cu m) | Bankfull discharge($m^3/s$) | Highest discharge recorded($m^3/s$) |
|---|---|---|---|---|
| Keolari | 19.872 | 763 | 3125 | 1670 |
| Kumhari | 71 410 | 1930 | 7887 | 3000 |
| Pauni | 280.330 | 12160 | 13524 | 18250 |
| Ashti | 572 146 | 19725 | 22560 | 28650 |

All discharges are based on the rates measured once per day.

The peak discharge varies year wise at all CWC stations (Fig 3..2). The figure shows the systematic increase of peak discharge at all stations up to 1991 and then it is decreased Hence, The highest peak discharge occurred in 1991 during the period of five years (1988-1992) at all stations. It is also revealed from the figure that the river has not exceeded the bankfull discharge at least in the last of five years. Further, at the upstream stations (Keolari and Kumhari ) bankfull discharge significantly exceeds the highest discharge recorded in the history of river (table 3.3) reflecting that no major flooding history at these stations. On the other hand, bankfull discharge is significantly lower than the highest discharge recorded for the downstream stations (Pauni and Ashti) reflecting the occasional overbank spilling.

## 3.4 Channel Sediment Characteristics

The channel sediment samples were collected from river at Pauni and Ashti stations. These samples were analyzed their grin size distribution using mechanical sieving for coarser fraction (sand). The results of the analysis are presented in the following sections.

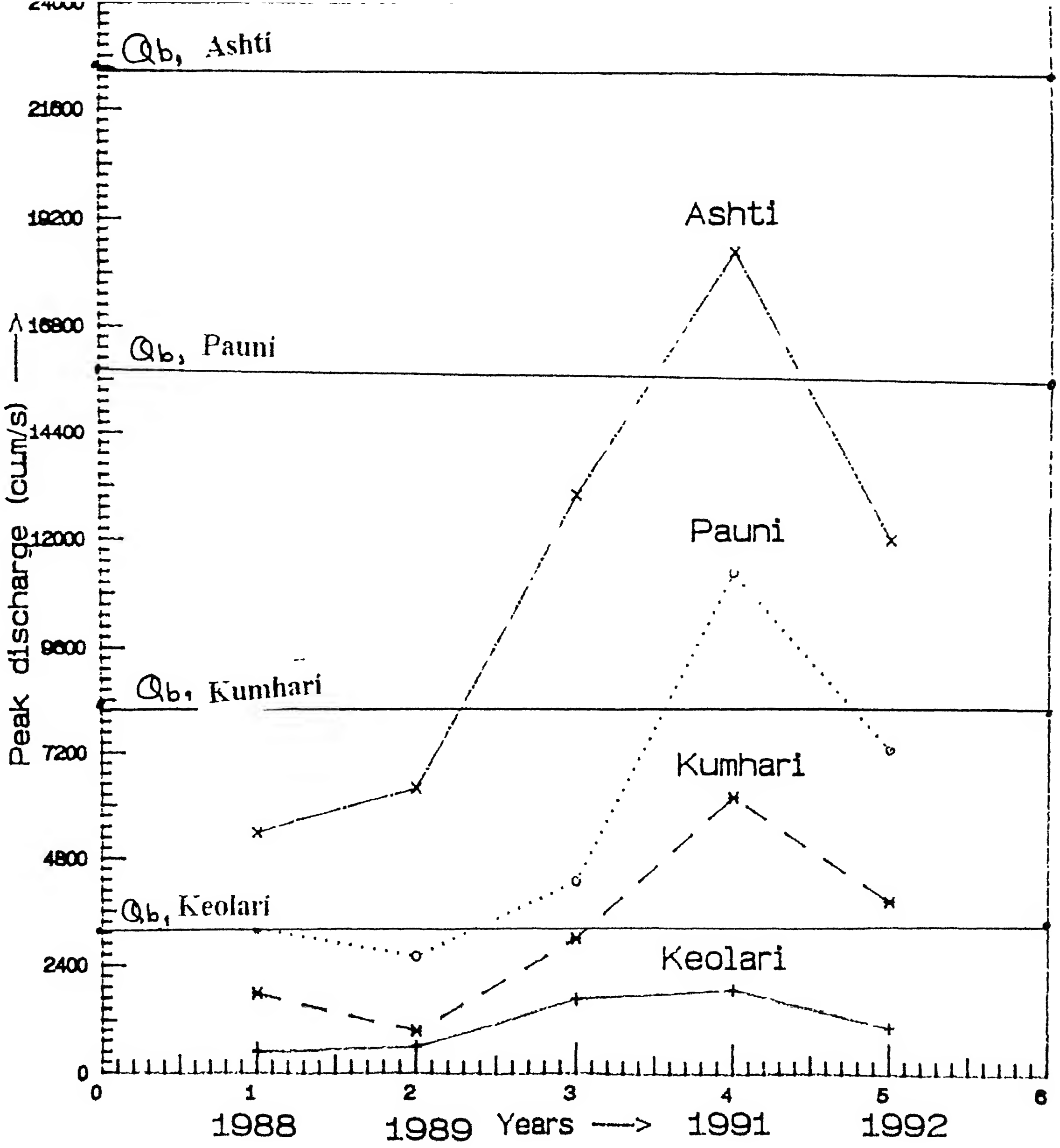


Fig. 3.2 The variation of peak discharge in five years.

## Table 3.4: Results of the mechanical sieve analysis

Sample at Pauni station

| Sieve size | Weight retained (gm) | % retained | Cumulative % | % Finer |
|---|---|---|---|---|
| 2.00mm | 10 | 2.10 | 2 10 | 97.90 |
| 1.00mm | 9 5 | 1.99 | 4.09 | 95.91 |
| 425 um | 81 7 | 17.33 | 21.22 | 78 78 |
| 212 um | 361 7 | 75 83 | 97.05 | 2.95 |
| 150 um | 5.1 | 1 07 | 98.12 | 1.88 |
| 75 um | 7 0 | -- | --- | -- |

Sample at Ashti station

| Sieve size | Weight retained (gm) | % retained | Cumulative % | % Finer |
|---|---|---|---|---|
| 2.00 mm | 0 | 0 | 0 | 100 |
| 1 00 mm | 0 | 0 | 0 | 100 |
| 425 um | 0.6 | 0.13 | 0 13 | 99 87 |
| 212 um | 405.9 | 89.21 | 89 47 | 10 53 |
| 150 um | 26.6 | 5.85 | 95.32 | 4 68 |
| 75 um | 14.6 | 3.21 | 98.53 | 1 47 |
| pan | 7.3 | - | - | - |

The following parameters are computed from an analysis of above table :

Average size of sediment $(d_a) = (d_{10} + d_{20} + \text{--------} + d_{90}) / 9$

Sorting Coefficient$(S_c) = d_{90} / d_{10}$

Uniformity Coefficient$(C_u) = d_{60} / d_{10}$

Where $d_{90}$ = The particle size corresponding to 90 % finer.

$d_{10}$ = The particle size corresponding to 10% finer.

$d_{60}$ = The particle size corresponding to 60 % finer.

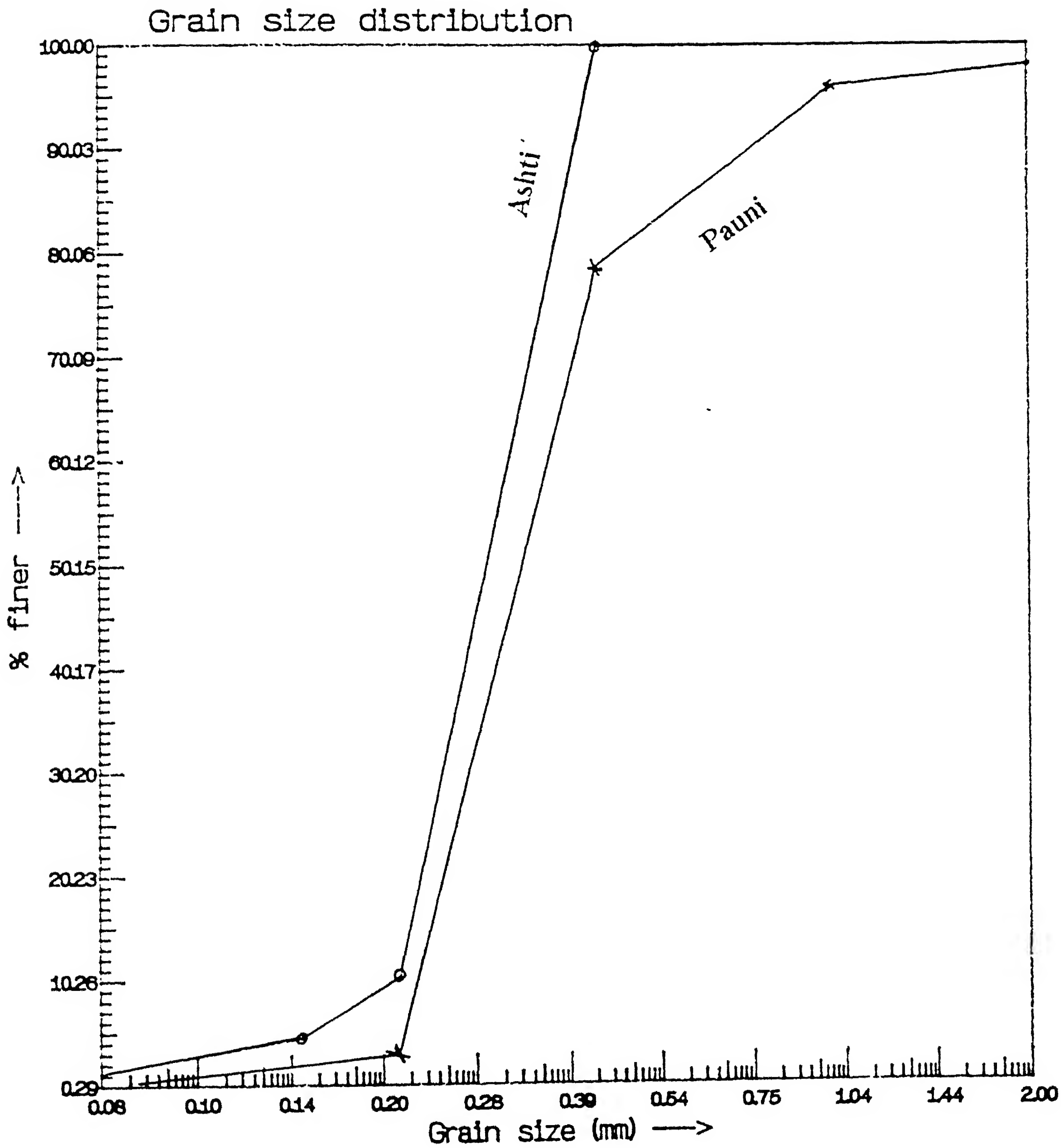


Fig. 3.3 : Grain size distribution curve

The parameters computed for above samples are given below:

**Table 3.5: Channel sediment characteristics**

| Parameters | Pauni | Ashti |
|---|---|---|
| $d_a$(mm) | 0.473 | 0 403 |
| Sc | 1.200 | 1.165 |
| $C_u$ | 1.548 | 1.400 |

The average size of sediment, sorting coefficient and uniformity coefficients are decreasing downstream of the Wainganga river (table 3.5) from Pauni and Ashti The grain size distribution curves for above samples are presented in Fig. 3.3

The interpretation drawn from the distribution curves are as follows.

1 At Pauni, percentage finer is zero for size 0.065 mm and very small quantity of channel sediment is retained on sieve size of 2.00 mm. Hence, the size of channel sediment is confined between 0.065 mm and 2.00 mm. The plot (Fig. 3.3) shows steep variation from 0.20 mm to 0.41 mm which indicates that large quantity is bounded in this limit. An average size of channel sediment at Pauni station is obtained as 0.473 mm.

2. At Ashti station, percentage finer is zero for size 0.07 mm and very small quantity of sediment is retained on sieve size of 0.425 mm. The plot shows the steep variation of sediment size from 0.22 mm to 0.32 mm reflecting that major quantity of sample is retained in this range. The average size of sediment is 0.27 mm lying in the range of sand (0.07 - 0.35 mm).

3. The gradual decrease in sediment size (table 3.5 ) indicates that the channel sediments are getting finer and finer from upstream to downstream. An approach of sorting coefficients and uniformity coefficients towards the unity shows that the sediments are becoming uniform and sorted along river in the downward direction reflecting insignificant contribution of sediment load by confluencing tributaries

### 3.5 Sediment Transport Characteristics Along The River

The dynamics of sediment transport complicate attempts to quantify both the influence of transport mode and intensity on channel form and the total denudational yield of solutes and sediments from the catchment. Suspended sediment and bed load transport are successively more discontinuous, responding variously to changes of stream discharges and sediment supply.

#### *3.5.1 Discharge-Sediment Concentration relationship*

Empirical hydraulic relations have been developed for the Wainganga river based on five years of data on water discharge and sediment concentration. Figures 3 4 to 3.6 show the plots between water discharge and sediment concentration for Pauni and Ashti stations. Separate plots have been generated for the coarse and medium size fraction (as defined by CWC). The empirical relations are not developed for fine sediment (wash load) because it is controlled by various local conditions apart from the discharge.

The general form of the equation developed for the coarse and medium fraction is,

$C = A\ Q^{M}$ Where C = suspended sediment concentration, Q = Water discharge, A and M are constants. The empirical values of A and M were derived by curve fitting using a software package ( table 3.6).

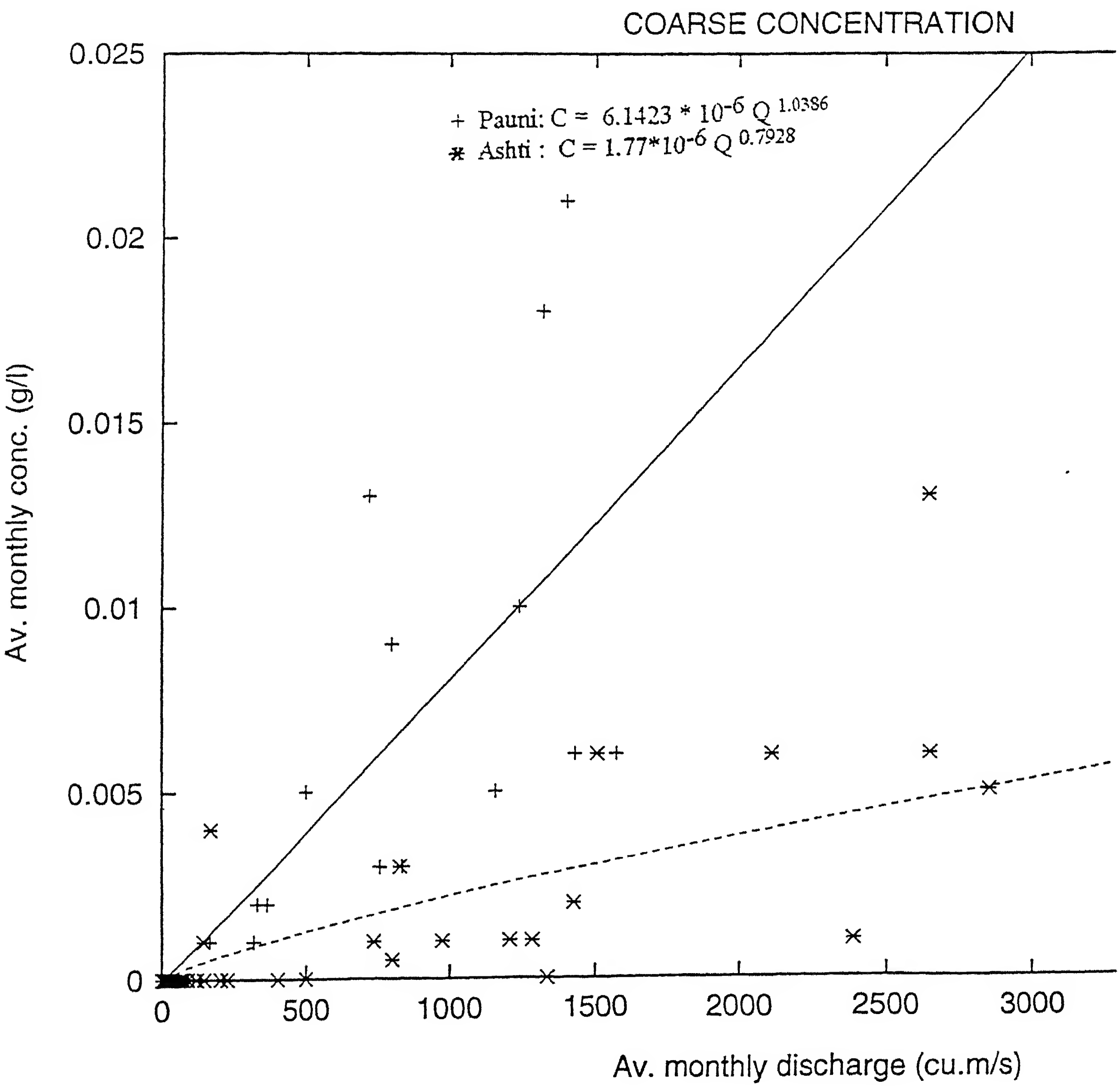


Fig. 3.4 Coarse sediment concentration at Pauni and Ashti

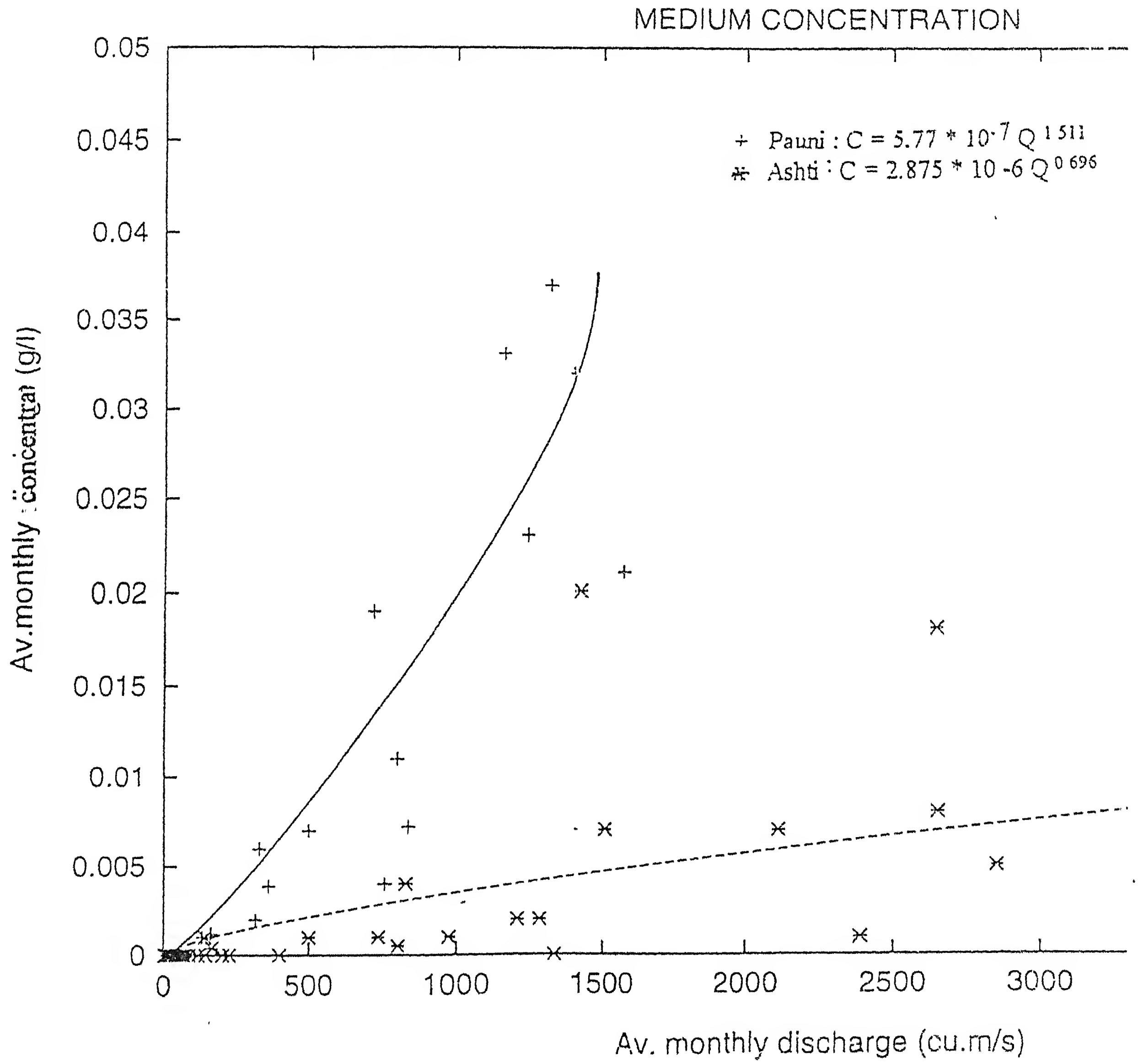


Fig. 3.5 Medium sediment concentration at Pauni and Ashti

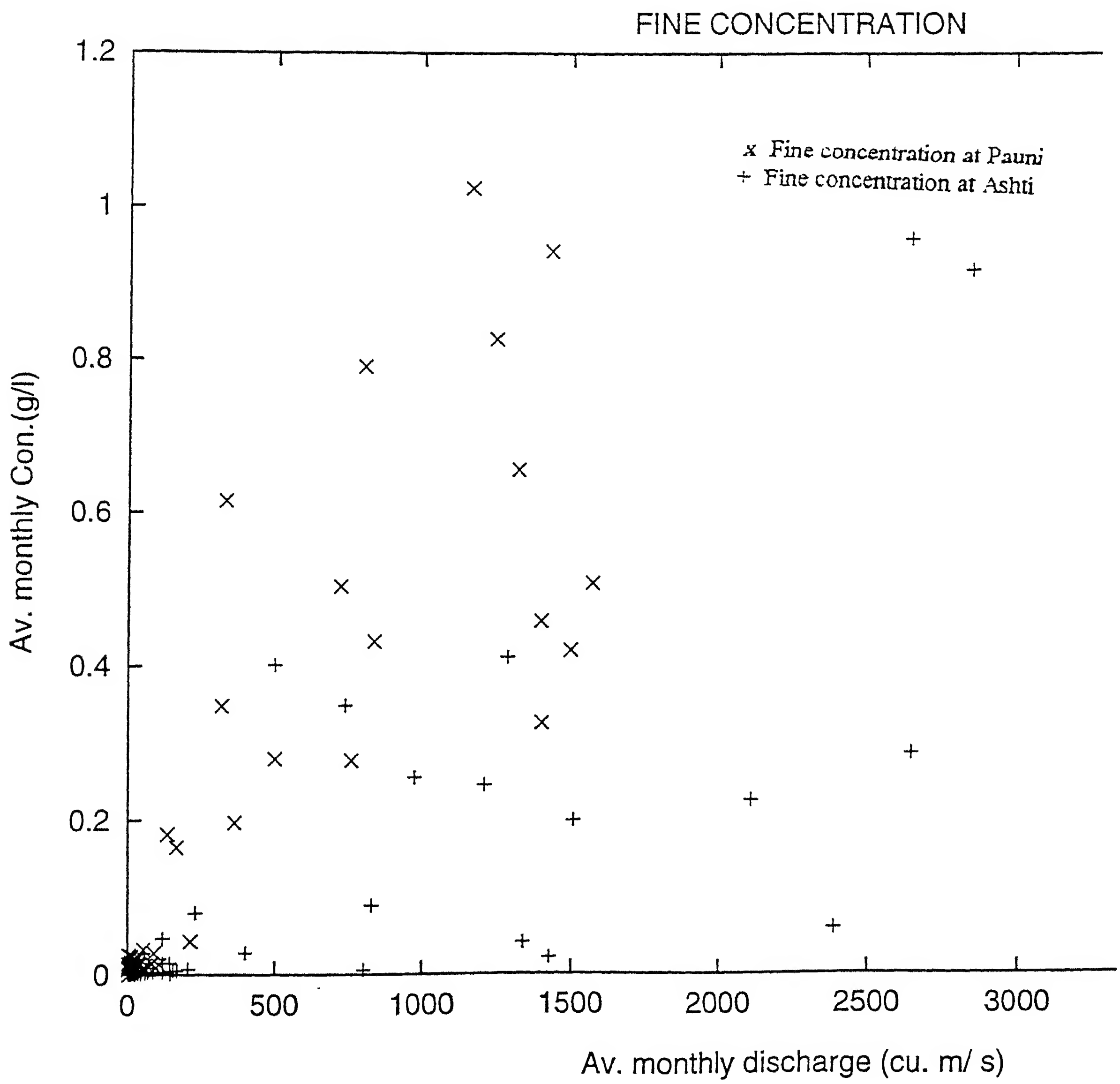


Fig. 3.6 Fine sediment concentration at Pauni and Ashti.

**Table 3.6 : Empirical relations of discharge versus sediment concentrations**

| Size Fraction | Pauni | Ashti |
|---|---|---|
| Coarse | $C = 6.1432 * 10^{-6} Q^{1.03857}$ | $C = 1.77 * 10^{-6} Q^{0.7928}$ |
| Medium | $C = 5.77 * 10^{-7} Q^{1.51104}$ | $C = 2.875 * 10^{-6} Q^{0.696}$ |

The equation for the coarse sediment ($d_a > 0.2$ mm) at Pauni station show that the coarse sediment concentration is directly proportional (m~1) to the water discharge but the coarse concentration at Ashti must be less than (m < 1) that of the Pauni station (Fig 3.4 ) The medium concentration (0.2 mm - 0.075 mm) is considerably reduced at Ashti as compared with Pauni station (Fig 3.5). The values of powers (m) are significantly different reflecting the considerable fall of medium sediment between Pauni and Ashti The fine sediment concentration is increasing at both stations with water discharge with very small fall of fine sediment at Ashti station (Fig. 3.6). It is observed from the plots that major contribution of total load is due to fine load (wash load ). This may be occurred because of the low discharges and insufficient gradient required to transport coarse and medium sediment in the river

These figures and empirical relations present that concentration of all size fractions is higher at Pauni than that of Ashti station. This effect may be because of the varied lithology at both stations. The reaches at Pauni region are covered with Alluvial soils while the reaches at Ashti region are covered with Precambrian hard rocks (granite gneisses). The alluvial soil is more susceptible to surface erosion and bank incising than the Precambrian rocks. Hence, sediment concentration is higher at Pauni than that of Ashti station.

### *3.5.2 Sediment Budgeting*

The total annual suspended load has been computed for upstream (Pauni) and downstream station (Ashti) and the data is presented in the table 3.7. Further, Fig. 3.7 shows the comparison of annual suspended load for both stations for the period 1988-1992 The total suspended load and coarse plus medium fraction of the suspended load have been plotted separately, which provides interesting observations Table 3.7 and Fig. 3 7 clearly indicate that the total suspended load is extremely variable over the years and between the stations perhaps reflecting successive aggradation and degradation phases Interestingly, the (coarse + medium) fraction of the suspended load is higher at upstream station (Pauni) than that at the downstream station (Ashti ). Sediment yield (sediment load transferred per unit area) has also been computed for both stations. Once again the sediment yield for the upstream station is higher than that of the downstream station, which support the popular belief that small river basin contribute higher sediment load (Subramanian et. al., 1989).

**Table 3.7: Total sediment load of five years.**

| Year | Total load at Pauni (m t/yr.) | Total load at Ashti (m t/ yr.) |
|---|---|---|
| 1988 | 11.955906 | 5.740880 |
| 1989 | 2.742397 | 3.911744 |
| 1990 | 13.270510 | 12.869566 |
| 1991 | 9.085237 | 6.039292 |
| 1992 | 4.055135 | 5.951426 |
| Total | 41.109185 | 34.513207 |
| Av. annual sediment load (m t/ yr.) | 8.2218837 | 6.902641 |
| Sediment yield (t/ $km^2$/yr.) | 231.47 | 135.37 |

Although there is no regular pattern of variation in the annual suspended load between the two stations, the load total suspended load transferred at the upstream

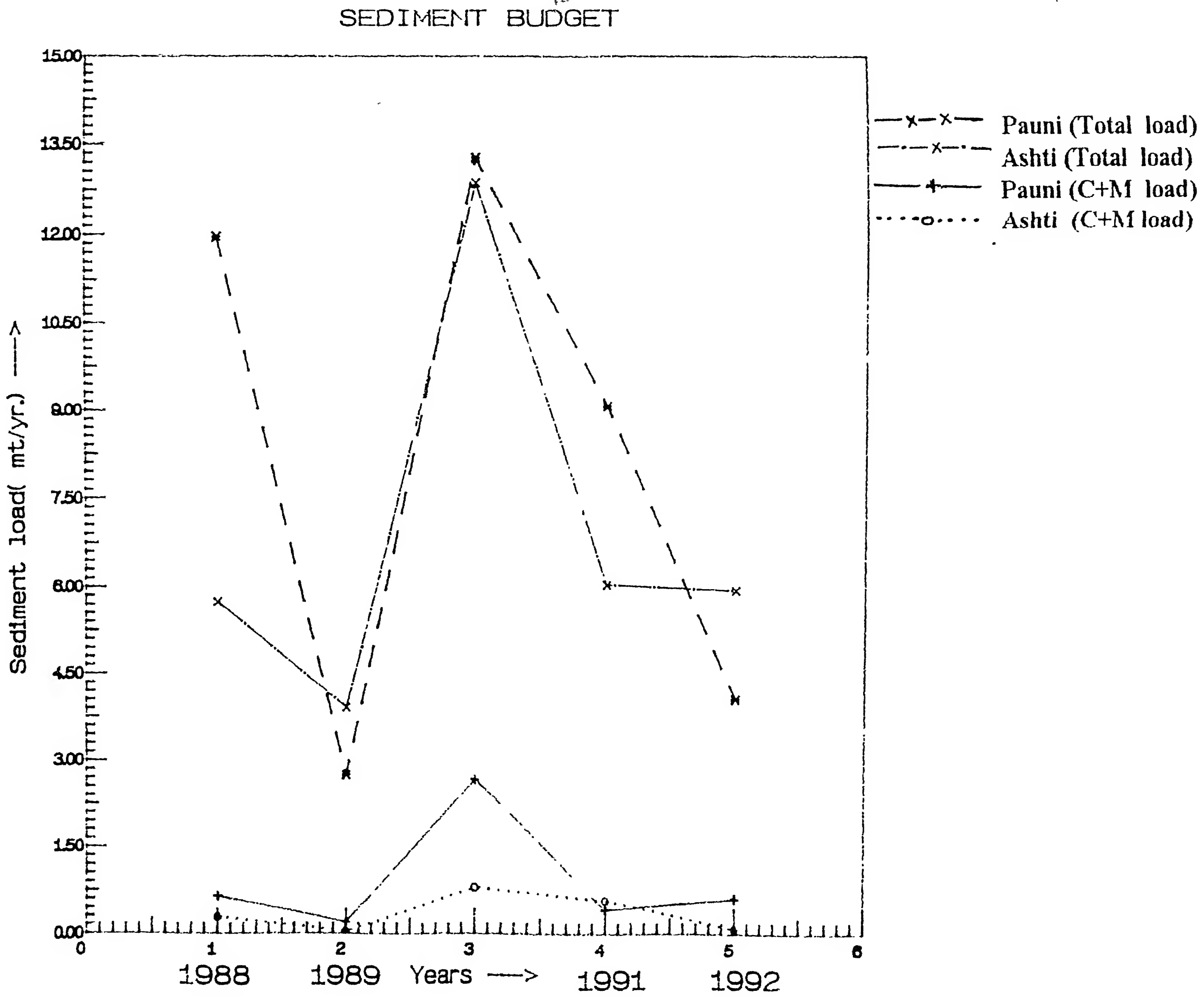


Fig. 3.7 Total and Coarse + Medium sediment load variation in five years

25·1

station is observed to be much more that at the downstream station, which is perhaps a reflection of sediment deposition pattern between the two stations.

Rate of aggradation = Difference in suspended load / ( reach length * No. of years)

= 6595978 / ( 220 * 5)

= 5.996 t / m/ yr.

The high value of rate of aggradation may be related to the longitudinal profile of the river between Pauni and Ashti ( Fig. 2.9). The gradients of the river bed Pauni and Ashti are 1 in 2663 and 1 in 2668 whereas the gradients at Keolari and Kumhari are 1 in 602 and 1 in 732 respectively. These gradients indicate a steep channel bed between Kumhari and Pauni and relatively flat channel bed between Pauni and Ashti stations. This sudden change in the channel gradient characteristics of the river may lead to the rapid deposition of sediment between Pauni and Ashti stations

# CHAPTER 4

# SUMMARY AND CONCLUSIONS

## 4.1 General

The Wainganga river is a major tributary of the Godavari river covering 51000 sq km area of the central India The river rises in the Pipariya (Amagarh) region in Madhya Pradesh traversing 606 km up to Ashti in Maharashtra state and confluences to Godavari river through the Pranhita river The monsoon climate experiencing Wainganga basin is overlain by Precambrian granite gneiss and Deccan traps for major part and Sakoli, Saucer, Alluvial soils and other rocks for very less part of the basin

## 4.2 Geological and Geomorphological Controls

The common drainage patterns encountered in the Wainganga basin are dendritic and rectangular controlled by uniform resistance of the rock and geologic structures respectively. In the Wainganga basin the major streams are oriented in the N-S and NNW-SSE directions which gives the presence of folds in the basin (Subbarao et al., 1980). The geomorphological map produced ( chapter two) shows the trend of major streams along one direction only because of the pronounced fold.

The sinuosity of the major reaches of the river just exceeds unity which shows that river is flowing almost straight because it is confined by very hard rocks. The upstream reaches of the Wainganga river exhibit higher sinuosity value than that of the downstream reaches reflecting the control of longitudinal gradient of the Wainganga river. It results in narrow and deep channel sections in the upstream and wide and shallow

channel sections in the downstream reaches. The braid-channel ratio is exceeding unity for some reaches which indicates the deposition of the sediment in these reaches as shown by field study. Hence it may be concluded that favorable factors for controlling the sediment deposition are existing. The present study reviews that sediment deposition is taking place because of the flat channel bed (section 2.5.3) and availability of sediment load between Pauni and Ashti station

### 4.3 Hydrology and Sediment Transport of the Wainganga river

The average monthly discharge of the river is maximum in the month of July and August and minimum in the month of April and May. The maximum discharge varies year to year (section 4.2). The average annual runoff is 762.7 M cu at Keolari, 1930 M cu. at Kumhari, 12160 M cu. m at Pauni and 19725 M cu. m at Ashti.

Although the water discharge is increasing in downstream but the sediment concentration is reduced. An empirical relations derived from the water discharge and sediment concentration show the higher concentration of fine sediment (>90%) at both Pauni and Ashti station This indicates that the fine sediment the dominant proportion of the total sediment load. The probable reason is that water discharge may not be sufficient to carry coarse and medium size sediment. It is also concluded from the empirical relations that the rate of fall of medium sediment is significant between Pauni and Ashti station. Hence the total sediment load at Pauni (upstream station) is higher than its downstream station (Ashti) which result in the aggradation of the sediment in between these stations at a rate of 5.996 t /m /yr.

During the deposition of sediment between Pauni and Ashti, there may be very less contribution of load tributaries because the sediment size, uniformity coefficient and

sorting coefficient are decreasing in the downward direction Hence the catchment yield mass transfer is more in the upstream part ( 231.47 tonnes/ $km^2$ / yr.) of the basin than downstream portion ( 135.37 tonnes / $km^2$ /yr.).

### 4.4 Comparison with other Indian rivers

The sediment transport of the Wainganga basin is compared with other Indian river as shown in the table 4.1.

**Table 4.1 Comparison of the sediment transport of the Wainganga river**

| Rivers | Stations | Area ($km^2$) | Annual discharge ($m^3$/sec) | Runoff | sediment load M t /yr | Sediment yield (t /yr./ $km^2$) |
|---|---|---|---|---|---|---|
| Wainganga | Pauni | 35529 | 280 | 12160 | 8.22 | 231.47 |
| Wainganga | Ashti | 50990 | 572 | 19725 | 6.90 | 135.37 |
| *Godavari | Rajhamundry | 313147 | 2925 | 92245 | 170 | 543 |
| *Mahanadi | Tikarapara | 88320 | 1726 | 54431 | 30.7 | 347 |
| *Narmada | Garudeshwar | 87892 | 1480 | 46673 | 69.7 | 793 |
| *Krishna | Vijaywada | 251360 | 1027 | 32397 | 4.0 | 16 |
| +Ganga | -------- | 1073 * $10^3$ | 15000 | --- | 1670 | 1560 |
| ++ Kosi | Baltara | 101 * $10^3$ | 1216 | --- | 43 | 430 |
| ++ Gandak | Dumariaghat | 46 * $10^3$ | 1529 | ---- | 79 | 1730 |
| ++ Kamla - Balan | Jhanjharpur | 9 * $10^3$ | 66 | ----- | 10 | 1110 |
| ++ Baghmati | Hayaghat | 13* $10^3$ | 156 | ---- | 11 | 840 |

Source: * Subramanian et. al. (1987), + Milliman & Meade (1983); ++Sinha & Friend (1994)

The average annual discharge of the Godavari river at Rajhamundry is significantly higher than that of the Wainganga river at Pauni and Ashti. Accordingly, the sediment load transferred by the Wainganga river at Pauni and Ashti is significantly lower than the sediment load transferred by Godavari river at Rajahmundry (at mouth ) reflecting that the Wainganga river contributes very small sediment load. The Wainganga river is major tributary of the Godavari constituting approximately 16 % catchment area

of the Godavri basin. However, it contributes only about 4 % of the total sediment load of the Godavari. Another interesting observation can be made from the table that total sediment load transferred by Krishna river at Vijaywada is lower than that of Wainganga river although catchment area is significantly higher than that of the Wainganga river

Further, the sinuosity and braid-channel ratio of the Wainganga river (present work) is smaller than that of the Himalayan rivers (Sinha and Friend, 1994). A distinct structural control on the morphology of the Wainganga river has caused straightening of the channel reaches resulting in the lower sinuosity values. The development of the multichannel system is not significant in the case of Wainganga river unlike to the Himalayan rivers which are strongly braided (Gandak and Kosi) This may be related to the availability of large quantities of sand size sediments in the case of Himalayan rivers. The Wainganga river has been shown to be low in coarse and medium sediment concentration.

The difference in sediment yield of the Wainganga river and the Himalayan rivers is striking. For example, Gandak has comparable catchment area to the Wainganga, even though the sediment yields are an order of magnitude different. This may be related to the lithology of the area being drained by the rivers as the Wainganga essential drains a hard rock terrain, the Gandak drains the alluvial plains of the north Bihar. Further, the water discharge is significantly higher in case of the Gandak. Therefore, the combined effect of huge discharge availability of loose material has resulted in higher sediment yield for the Gandak than the Wainganga river even though their catchment areas are approximately same.

### 4.5 Concluding Remarks and Future work

The tear shaped Wainganga river basin consists of mostly hard rock terrain i.e. granite gneisses and Deccan Traps. The drainage pattern is strongly controlled by geologic structures i.e. fault and fold. The Wainganga river is almost straight in significantly long reaches and it mostly displays single-channel morphology with low sinuosities. Interesting variations in hydrological and sediment characteristics are observed in space as well in time Although water discharge is increasing downstream, even then the sediment load transferred at upstream stations is higher than downstream station which is interpreted to be a cumulative effect of a variety of factors viz. lithology, land cover and deposition patterns. The fine sediments constitute a major proportion of the total sediment load which are essentially wash load and result from reworking and resuspension of the earlier deposits. Further. the low values of water discharge and particularly the large fluctuations in monsoonal and lean period discharge causes deposition of the coarse and medium fractions of the sediment load; the rate of fall of medium sediments is more than that of the coarse sediments.

In the Wainganga basin the future work may be emphasized on the following :

1. The tectonic control on drainage development may be studied in much more detail particularly through satellite remote sensing data.
2. Although no direct evidence of neotectonic activity is visible in the area, the possibility of its effect on the hydrological and sediment transport behaviour of the Wainganga and other rivers may be worth exploring.
3. The sediment budgeting with respect to particular lithology viz. Deccan Traps, Precambrian rocks, Sakoli group, Vindhyan group and subrecent to recent alluvial soils may yield interesting information related to erodibility of the catchment.
4. Long-term data analysis may be necessary to establish the aggradation and degradation phases along the Wainganga river.

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